Modeling & Simulation for Affordable Manufacturing
Technology Roadmapping Workshop

Relevant R&D Abstracts
10 May 2002

FOREWORD

All project information in this document is taken from MAST: the Manufacturing Analyst for Science & Technology, an IMTI members-only information resource. Data included in this report originated from several databases and websites including: National Science Foundation Grants and Awards, Rand's Ra-DiUS, DOE Industries of the Future, DOE Research and Development, Navy Best Manufacturing Practices, NIST Advanced Technology Program Awards, Department of Defense DDR&E S&T Plan, DARPA, the Navy ManTech Project Book, and others.

The abstracts herein are not intended to represent a complete view of all ongoing federal R&D relative to modeling and simulation, but rather to highlight the diversity of current R&D projects for which information is readily available from open sources without restrictions on dissemination.

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1.0 IMTI Roadmap for Modeling & Simulation – Executive Summary

The following is excerpted from the IMTI Roadmap for Modeling & Simulation, published in July 2000. The full text of the document is available on the IMTI website at **www.imti21.org**

Modeling & Simulation: the Engine and Control Systems for Lean, Agile, Responsive Manufacturing

Modeling and simulation are emerging as key technologies to support manufacturing in the 21st century, and no other technology offers more potential than M&S for improving products, perfecting processes, reducing design-to-manufacturing cycle time, and reducing product realization costs. Although specialists currently use M&S tools on a case-specific basis to help design complex products and processes, use of M&S tools other than basic computer-aided design/engineering (CAD/CAE) applications is largely limited to solving specialized design and production problems.

The real value of M&S tools is their ability to capture and represent knowledge to make confident predictions – predictions to drive product design, process design and execution, and management of the enterprise. Product and process development has historically been accomplished through testing designs to see how well they work, then modifying the design and testing it again. This test/ evaluate/modify phase consumes a vastly disproportionate share of the time and cost required to move a product from concept to delivery.

These costs can be significantly reduced by investing more in the initial design, by using M&S tools to optimize products and processes in the virtual realm before committing resources to physical production.

Beyond design, simulation tools can greatly help improve the efficiency of manufacturing processes. For example, being able to accurately simulate the performance of a device over a range of temperatures can eliminate the need for lengthy temperature testing and expensive test facilities. In the electronics industry, accurate models of the process of epitaxial growth help maximize production yields for microchip wafer fabrication

The Boeing 777 and Dodge Viper are outstanding examples of how M&S tools can greatly reduce the cost and time of bringing products to market. The 777, the first jetliner to be designed entirely with 3-D modeling technology, used digital preassembly and concurrent collaborative engineering to eliminate the need for full-scale mockups, improve quality, and reduce changes and errors – all of which contributed to significant reductions in cost and time compared to conventional techniques.

The savings provided by M&S are significant. In the automotive industry, M&S tools have helped reduce the time required to move a new car design from the concept stage to the production line from 3 years to about 14 months. The DoD's Joint Strike Fighter (JSF) program expects to apply advanced M&S technologies to reduce aircraft development costs by 50%.

In the IMTI vision, M&S tools will couple evolutionary knowledge bases (that continuously learn and grow using genetic principles) with validated, science-based first principles models. This deep understanding will enable "continuum modeling" of products and processes down as far as the molecular level, enabling prediction of macro behavior that takes into account the cumulative effects of all factors at the micro level.

Product and process models will be smart, self-correcting, learning systems that adapt in real time based on changing conditions and past experience. M&S systems will provide the knowledge and rules (constraints) to enable individuals to perform their functions within the enterprise to the best of their ability, with no specialized training.

As described in the IMTI *Roadmap for Information Systems*, the M&S systems of the future will be interconnected and supported by a robust and seamless information infrastructure that interfaces these systems to internal and external sources of accurate, real-time data. This will enable products, processes, and facilities to be designed, optimized and validated entirely in the virtual realm.

Supporting analytical tools will be invoked automatically and run near-instantaneously in the background, and computer-based advisors will be available at the touch of a button or a spoken command to aid designers and managers in evaluating options, understanding issues, and making the best decisions.

This robust M&S infrastructure will enable creation and operation of totally integrated enterprise control systems, where product models, process models, and resource models interconnected within an overarching master enterprise model interact to drive and control the living enterprise – fed by accurate, real-time data drawn from the lowest levels and farthest reaches of the enterprise. The desktop PCs and information reporting systems of today will be replaced by "virtual cockpits" where executives, managers, designers, and administrators interact with the living enterprise model at the appropriate level to:

- Have instant, clear, accurate visibility into the status and performance of their operations.

- Quickly evaluate issues and options to determine the best solutions.

- Instantly propagate changes to all parts of the enterprise, and automatically update the living enterprise model.

Other specific benefits of the next-generation M&S systems and tools inherent to the IMTI vision include:

- Rapid evaluation of alternatives, trends, and risks, based on accurate data, to confidently predict the results of contemplated actions.

- Greatly shortened product development time and cost, by eliminating the need for physical prototyping.

- Rapid optimization of new product designs, processes and equipment, and business operations, to maximize efficiency and profitability while reducing all forms of waste.

- Automatic producibility, affordability, and other critical analyses, running in real or near-real time, and intelligent decision support to ensure both the products and the processes used to create them are the best they can be.

- Significant reduction of economical order quantities, enabling "mass customization" to better meet the needs of individual customers while enhancing profitability.

- Fast, accurate exploration of many more product and process design options, to increase value to the customer and reduce concept-to-production time and cost.

- Ubiquitous service throughout the enterprise, enabled by low-cost, interoperable tools. This will also enable rapid, seamless integration of new supply chain relationships to pursue new opportunities.

- Comprehensive, globally accessible knowledge bases of validated plug-and-play models, simulations, and supporting tools upon which all companies can draw, thus greatly reducing the cost of acquiring and implementing M&S capabilities.

Table 1 on the following page provides a summary-level view of where we are today, from the standpoint of the current state of art and practice, and where we want to go. The goals reflected in the "2015 Vision" column encompass most of the goals identified in the IMTI *Roadmap for Modeling & Simulation*, and readers are encouraged to read the full document for a deeper understanding of these requirements.

Table 1.
Modeling & Simulation: Where Are We Now, and Where are We Going?

Manufacturing Function	Current State of Art/Practice	IMTI 2015 Vision
Product Modeling & Simulation Functions		
Physical Representation	• Solid models of nominal shapes; limited ability to accurately model complex interfaces, many attributes represented by symbols & notes • Unable to capture design intent or product functionality; limited ability to translate design to actual product • Limited product data exchange or across different domains • Complex tools requiring high skill & long processing times	• Object-oriented and feature-based models scaleable from micro to macro levels and containing all product info • Complete interoperability between physical models • Direct linkage to prototyping systems • Collaborative modeling & simulation using integrated environments
Performance	• Modeling of electrical performance more advanced than mechanical performance • Highly specialized applications with tremendous & complex computational demands – high cost & complexity • Poor understanding of underlying physics	• Performance design advisors and fast automatic performance optimization • Performance modeling & assessment tools plug-compatible with design systems • Multivariate performance analysis
Cost/Affordability	• Bottoms-up cost modeling from component level; no linkage to actual, real-time data • Custom cost models or generic tools (e.g., spreadsheet apps or database-driven simulations) ; specialized tools tailorable to similar processes with many variables	• Cost data available on commodities & downstream life-cycle costs • Performance-based cost modeling • Enterprise-wide cost models
Producibility	• Limited to assessment based on parts count, number of part surfaces, or known chemistry; no tools for assessing non-physical factors • Lengthy simulation times limit number of alternatives	• Producibility alternatives automatically modeled during all development phases; autonomous agents to track producibility-related changes for products • Producibility models interoperate with other technical & business models
Life Cycle Considerations	• Little or no modeling & simulation of life cycle issues • Limited modeling of environmental attributes (e.g., product "greenness") • Some modeling of product support costs	• Environmental & support analytical modules included in or interfaced to product M&S applications • All life-cycle considerations included in product models, such as recycling, disassembly & disposal
Process Modeling & Simulation Functions		
Material Processing	• Excellent analytical M&S capabilities in continuous processing industries (e.g., chemicals) ; some knowledge-based advisory systems in use • Good base of material models for simple & traditional materials; simplified models & assumptions; data from handbooks • Applications based on empirical data or past "art"; high costs & special skill needs limit use • Emerging base of material models for newer nontraditional processes (e.g., composites)	• Automated process model creation from design models & enterprise data • Validated, science-based models for all materials • Model repository for reuse • Open, universal framework for M&S standards & model interoperability • Collaborative distributed analysis & simulation systems supporting global distributed manufacturing enterprises
Assembly/Disassembly/ Reassembly	• Good electronics assembly modeling applications • Assembly line balancing (workflow optimization) • Tolerance & interference modeling in limited use • Few standards	• Immersive VR system for assembly modeling & simulation, with automated optimization • Integrated links to production systems for real-time troubleshooting, change response, & optimization across enterprise & supply chain

Table 1. (continued)
Modeling & Simulation: Where Are We Now, and Where are We Going?

Manufacturing Function	Current State of Art/Practice	IMTI 2015 Vision
Quality, Test & Evaluation	• Models from empirical data for statistical control • Limited modeling of dimensional metrology	• Virtual system for test & evaluation modeling coupled to test & evaluation knowledge bases • Automated model generation from specifications
Packaging	• Product flow models coupled with part tracking systems • Models for packaging design for some industries (e.g., defense, food, chemicals)	• On-line virtual system for modeling packaging, including environmental impacts
Remanufacture	• Limited, specialized applications for specific product types • Existing process modeling apps used to evaluate remanufacturability of designs (not tailored for remanufacturing)	• "Reverse engineering" modules to optimize life-cycle performance and re-use • Robust applications integrating all aspects of remanufacturing in initial product and process design stages
Enterprise Modeling & Simulation Functions		
Strategic Positioning	• Little or no modeling & simulation • Limited use of simple, "homegrown" models	• Strategic decision models with real-time data links • Easy, transparent modeling & simulation
Market Assessment & Positioning	• Primarily use of spreadsheets • Some market share modeling & gaming simulations	• Domain specific models with links to external & internal information sources • Extensive market assessment models & tools
Risk Management	• Little or no automated modeling • Spreadsheet-based models based on individual expertise	• Domain & function specific risk models • Risk assessment & avoidance models
Financial/Cost Management	• Spreadsheet-based financial modeling • Deterministic cost models	• Predictive cost modeling • Integrated cost & profitability models
Resource Management	• Many tools for specific uses; expensive data collection • No common standards or integration frameworks	• Enterprise-wide resource models • Extended enterprise resource models
Quality Management	• Limited "cost of quality" modeling	• Quality impact assessment & tradeoff tools • Quality no longer a discriminator – all excellent
Enterprise Architecture Management	• Little or no modeling • Structured models (e.g., IDEF & GRAF)	• Generic enterprise architectures, metrics & modeling tools • Full enterprise architecture models
Extended Enterprise Management	• Little or no modeling • Supply chain modeling using proprietary or custom systems	• Techniques for modeling functions across the supply chain • Automated knowledge management across extended enterprise
Operations Resource Management	• Many tools available for specific functions or resources • Large, complex, hierarchical models	• Tools & standards for model building & integration • In-depth resource management models
Performance Management	• Cost & schedule performance models • Larger custom models	• Accurate data collection techniques for model building • Self-optimizing simulation models
Factory Operations	• Many domain-specific models • Expensive & time-consuming systems	• Data collection techniques, standards & frameworks • Virtual factory models using real-time data
Facility Infrastructure Management	• Domain-specific systems • Some ERP systems have infrastructure features	• Standard taxonomies & generic infrastructure models • Integrated physical control & performance models

It is important to note that there is a very wide range separating the current "state of practice" and "state of the art." Many of the systems and processes now being pioneered by leading-edge organizations are closely attuned to the IMTI vision, and it is our expectation that these capabilities will evolve to wide-spread use over the next 5 to 10 years.

The "Nuggets" of Modeling & Simulation for Manufacturing

The IMTI *Roadmap for Modeling & Simulation* identifies some 40 top-level goals and more than 170 supporting requirements and tasks to meet the needs of future manufacturing enterprises. However, out of these goals and requirements there are 10 "nuggets" – critical capabilities or attributes – that underpin the IMTI vision and which offer the greatest return on investment by virtue of their broad applicability to industry:

• **Nugget #1: Micro to Macro Continuum Modeling** – A major drawback of current product and process models and simulations is that they are generally valid only for the exact parameters around which they were built, and are not valid at larger scales. Future models will be infinitely scaleable, assuring the ability to create models on a manageable scale that are valid when extrapolated to the real world.

• **Nugget #2: Science-Based Models Integrated with Living Knowledge/Experience Bases** – The models and simulations of the future will be built on a foundation of deep understand of first principles, providing perfect fidelity with the real world they are designed to emulate. They will be able to adapt and learn based on real-world experience, capturing the insights and lessons learned of their users.

• **Nugget #3: M&S Is Rule, Not Exception** – M&S technology will evolve from a specialized, application-specific troubleshooting tool to a ubiquitous capability that pervades and supports all functions of the manufacturing enterprise. Executives, managers, supervisors, and manufacturing staff will interact with the manufacturing enterprise through a user-friendly virtual interface on their desktop PC to a living enterprise model that links them to real-time information about all of the operations, activities, and processes relevant to their jobs. Proliferation of high-fidelity, generic product and process models, coupled with intelligent software for creation and tuning of models and simulations, will make M&S tools inexpensive and easy to use.

• **Nugget #4: Intelligent Design & Analysis Advisors** – Product and process developers will tremendously increase the productivity, speed, and quality of their work with aid of intelligent software-based advisors that assist in every step of the product realization cycle. These advisors will draw on an ever-expanding knowledge base of scientific principles and captured experience (lessons learned) to help designers work around obstacles, avoid false starts, and optimize their work product at every stage of its evolution.

• **Nugget #5: M&S as Real-Time Enterprise Controller** – As modeling and simulation become pervasive, manufacturers will be able to build a real-time, accurate simulation model of the entire enterprise, including all of its products, processes, resources, assets, constraints, and requirements. In its ultimate form, the living enterprise model will be the control interface for all enterprise operations, monitoring real-time performance and status of every operation. Managers will interface with the enterprise model to evaluate performance, identify issues and concerns, and assess outcomes of contemplated actions, ensuring that enterprise performance is continuously optimized in response to changing requirements and conditions.

• **Nugget #6: Smart, Self-Learning Models** – Next-generation models and simulations will "understand" their own needs, goals, and requirements, and will interact with other models and simulations – and the enterprise knowledge bases – to continuously improve their depth, fidelity, and performance. Product models, for example, will be "smart" enough to optimize themselves for producibility, maintainability, and similar attributes based on real-time access to information on factors such as availability of components and raw materials, shop capacity, and individual process equipment and unit operation capabilities and workloads.

• **Nugget #7: Open, Shared Repositories & Validation Centers** – The creation of science-based models and simulations for widely used materials and processes will give rise to the establishment of national and international libraries of validated models and simulations that can be shared by many manufacturers across different sectors. This will drastically reduce a manufacturer's cost and time in developing models and simulations to support critical business requirements. Open access to common process and product models and M&S tools will also enable rapid integration of new partners and supply chain members to pursue new opportunities.

• **Nugget #8: Integrated, Robust Product & Process Models Supporting All Domains & Applications** – M&S will move from the product and process domains to support all facets of the manufacturing enterprise. Product models will be robust, high-fidelity representations that capture all relevant attributes of the product, from the molecular composition of its materials to the physics of its interactions in the manufacturing process and in its real-world use. Manufacturing and business process models will have similar high fidelity, and all models will be able to integrate to enable creation of "macro models" that accurately represent end-to-end processes, collections of processes, and the total enterprise. This will enable users to accurately predict how the effects of a change will ripple throughout the enterprise, and thus assure that all decisions are made based on a clear understanding of advantages, disadvantages, risks, and probable outcomes.

• **Nugget #9: Total, Seamless Model Interoperability** – Future models and simulations will be transparently compatible, able to plug-and-play via self-describing interfaces, and require no outlay of resources for integration or tuning. Every product and process model will understand its own behavior, its own input needs, and its own output capabilities, such that when a new element is added to the system (e.g., a process control sensor), it will negotiate with the models of all other elements of the system to "fit in" with no human assistance.

• **Nugget #10: Real-Time, Interactive, Performance-Based Models** – Future models and simulations will be linked via enterprise information systems to all data they need to remain current based on changing business considerations. Product models, for example, will be able to link to real-time material and labor cost databases so as to provide continuous visibility of actual product costs and be able to alert product managers when a changed parameter (e.g., increased price for a constituent material) requires attention (e.g., a change to a lower-cost material).

Achievement of these cross-cutting goals will have a major impact on manufacturing enterprises, enabling them to:

- Reduce the cost of developing and manufacturing products

- Enhance product quality and reliability

- Reduce the time required to move new products from concept to market

- Improve responsiveness to changes in customer needs

- Enhance ability to establish competitive position and increase market share

- More effectively manage capital investments (and therefore, increase return on investment).

2.0 Overview of DoD R&D Projects Related to Modeling & Simulation for Manufacturing

Title: **Accelerated Insertion of Materials**

Total Award Funding: $1,500K

Currently, the development of a designer knowledge base (which incorporates design allowables, reliability, manufacturing, reproducibility, and other essential information) is a time-consuming and costly endeavor. Consequently, new material insertion into production hardware is extremely difficult, typically taking 15-20 years (if it is successful at all). Emerging efforts in materials modeling are leading to incremental improvements in specific areas (e.g., materials processing and mechanical behavior). DARPA believes that the time-scale between the development of a new material and its implementation into production can be significantly shortened only through a revolutionary change in materials development methodologies.

The Accelerated Insertion of Materials program will create and validate new approaches for materials development that will accelerate the insertion of materials into production hardware. This is to be accomplished by establishing approaches to use the required technical content and fidelity of the "designer knowledge base" to drive the optimized development/use of models and experiments. Critical to this effort will be understanding how to effectively use materials models, how to link them across various length and time scales, and how to couple them with an optimized series of experiments to yield the appropriate information for the designer. Validation of the developed approaches will focus on material systems of interest to the DoD.

Eight universities, the DoD research and development arm, and an engine manufacturer have embarked on a new program to meet the 3-5 year goal. Itself a 10-year effort, the Accelerated Insertion of Materials (AIM) program will include cataloging the fundamental properties of materials and creating computer models to predict performance under widely varied conditions.

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PARTICIPATING ORGANIZATIONS:

Defense Advanced Research Projects Agency
Air Force Research Laboratory
Northwestern University
Lehigh University
Massachusetts Institute of Technology
University of Connecticut
Drexel University
University of Michigan
Carnegie Mellon University
Michigan Technological University

Title: **Integration of Empirical and Mechanistic Strength Models and Microstructural Distributions with Production and Design Databases**

Materials technologies are enabling in many Industries and ever-growing demands of the market place for accelerated product development have placed increasing pressure on the incorporation of new materials. Windows of opportunity for insertion are becoming rarer and unless a material is essentially production ready it will be unacceptable for use to system designers. Pratt & Whitney in response to the Accelerated Insertion of Materials (AIM) initiative, has assembled a team of industrial, academic and government technologists to develop a methodology realigning material development and certification with product requirements. The approach is to build a series of linked simulation tools that when coupled with selected experimentation, can provide the necessary information to the designer more rapidly and accurately than the current empirically based procedure.

POINT OF CONTACT: John J. Schirra

PARTICIPATING ORGANIZATION:

Pratt & Whitney

Title: **Materials Development Digitization-AIM Principles Applied to Alloy Development for Investment Cast Gas Turbine Buckets**

Work in progress at General Electric includes activities to 1) develop and demonstrate a hybrid experimental-computational approach to reduce cycle-time for the development of new alloys and processes; 2) integrate existing materials models and experimental databases with design of experiment (DOE) and optimization software; and 3) execute the macroscopic GE AIM (Accelerated Insertion of Materials) philosophy using turbine bucket alloy development as the pilot application. Automation of materials development requires modeling of chemistry and microstructural effects on attributes that are critical to design and life prediction of complex engineering components. The controlled nature of the manufacturing process on investment cast parts makes this area an ideal candidate for demonstrating early successes in the application of automated alloy development. It represents a unique case where the microstructural and processing variations are minimal, and thus the number of independent variables are reduced enough to allow incorporation of alloy chemistry into modeling. Emphasis is being placed on new tools and new understanding that will minimize the iterations in materials design that currently take place after the initial alloy screening phase in an alloy development program. These are the iterations most like to substantially lengthen the insertion cycle for a new alloy. A system is being built to incorporate designer input at the earliest stage of alloy development, and to allow the user to vary that input to tailor it towards different applications. The predictive capability is a combination of rules-based and physics-based models that are envisioned to improve from mostly rules-based to mostly physics based as time goes by. The system would allow users to select their personal preferences where competing models exist.

POINT OF CONTACT: M.F. Henry

PARTICIPATING ORGANIZATION:

General Electric Corporation

Title: **Analytic Methods to Cycle Time for New Composite Material Systems**

MSC is a subcontractor to Boeing on a DARPA (Defense Advanced Research Projects Agency) program titled "Accelerated Insertion of Materials." The program focuses on using analytic methods to reduce the time needed to introduce a new composite material system into products. MSC developed a series of *Mathematica* packages that go from micromechanical analyses of composites to structural subelements of an aircraft. A major goal of the program was linking all levels of these analyses together. The *Mathematica* language is ideal for developing data structures such that the output from one operation directly becomes the input for the next.

PARTICIPATING ORGANIZATION:

Materials Sciences Corporation

Title: **The Accelerated Insertion of Materials-Composites Program**
Carbon fiber reinforced composites offer significant improvements in performance, affordability, and durability to aerospace structures providing lighter weight and better mechanical properties compared to metals. Their application on air vehicles over the last thirty years has resulted in greater mission capability allowing added munitions and avionics, greater flight range, and other benefits. Developing and qualifying composite materials and aerostructures, though, is time consuming and expensive requiring the testing of thousand of specimens at a cost of millions of dollars. The DARPA Accelerated Insertion of Materials – Composites (AIM-C) program seeks to develop and validate new methods to significantly reduced the time and cost of inserting composite materials in DoD systems. This is accomplished by establishing approaches to better use test verified computational analysis, integrated engineering simulations, virtual testing, and intelligent DOE to develop a material's designer knowledge base (which incorporates design allowables, manufacturing, production readiness, supportability, and other essential information) more efficiently. Critical to the effort is understanding how to effectively use materials, process, and failure prediction models, how to link them across various length and time scales, and how to couple them with experiments to yield the appropriate data with required confidence limits.

POINT OF CONTACT: Raymond Meilunas

PARTICIPATING ORGANIZATION:

Naval Air Systems Command

A0773

Title: **Enhanced Powder Metallurgy Processing of Superalloys for Aircraft Engine Components**

Start Date: 10/01/1996

End Date: 06/01/2000

Total Activity Funding: $4,500K

Abstract: The objective of this project is to demonstrate the applicability of enhanced powder metallurgy (P/M) processing of superalloys for cost-effective production of superior quality weapons system components, specifically turbine disks for aircraft engines.

Enhanced P/M processing combines technologies for powder preparation, hot isostatic pressing (HIP), extrusion, ultrasonic inspection, and isothermal forging to improve quality and reduce the cost of super-

alloy turbine disks. Acquisition cost savings of at least 20 percent have been demonstrated using enhanced P/M processing of Udimet 720 turbine disks for the T800 engine in Army's Manufacturing Science & Technology Institute Project (DAAJ09-93-C-0518). Cost savings for the Navy's T406 turbine disks are projected at up to 25 percent. This represents a savings of $38 million based on the Navy / Allison life cycle cost model. The enhanced P/M processing technology developed will also be applicable to all US built commercial aircraft engines.

Navy and DoD aircraft programs such as the T406 engine used in the V-22 Osprey and the T800 engine used in the Comanche helicopter will benefit from this project.

Technical Approach

This project addresses enhanced P/M processing technologies for production of T406 turbine disks and other aircraft components from Udimet 720 and other superalloy grades. This technology will be demonstrated by fabricating and testing T406 disks as qualification level hardware. The following activities comprise the technology assessment and demonstration phases of this project.

(1) Additional superalloy grades and aircraft component applications (other than the Udimet 720 alloy T406 disks) will be identified and evaluated based on input obtained from the Navy and engine manufacturers interacting through the enhanced P/M users group. This group will also receive periodic updates on the status of the technology demonstration and assessment activities.

(2) A subcontractor will be engaged to (i) prepare and characterize -270 mesh Udimet 720 powder for use in producing HIP manufactured and extruded P/M billet material, and (ii) develop necessary seeding and ultrasonic inspection techniques.

(3) A qualified forging vendor (Ladish) will isothermal forge and heat treat T406 disk preforms. This effort will include forging die design and analysis, preform ultrasonic inspection, and development of thermomechanical processing practices.

(4) The T406 engine manufacturer (Allison Engine Company) will complete machining, material testing, cyclic spin and burst testing of the T406 disks, and also perform specification development, and validation of cost / benefit projection tasks;

(5) Technology assessment activities will focus on verification, documentation, and modeling for optimization of the technologies comprising enhanced P/M processing. These technologies include powder production and characterization, HIP processing, extrusion, isothermal forging and heat treatment, machining, ultrasonic inspection, and testing.

Deliverables/Implementation

Project deliverables include reports documenting the technical approach and accomplishments, prototype hardware for qualification testing, and specifications for manufacturing P/M Udimet 720 turbine disks for the T406 engine as well as other applications for alloy grades and components which are of interest to the Navy. Initial implementation of enhanced P/M processing will be for T406 turbine disks for the V-22 Osprey. The T406 Engine Program Office, at its own cost, will be responsible for certifying the technology for T406 engine component production. Allison Engine Company and Ladish Company will be integrally involved in project execution and implementation of the technology.

Status This project involves a team comprised of Naval Air Systems Command (NAVAIR) representatives, the T406 Engine Program Office, the National Center for Excellence in Metalworking Technology, Allison Engine Company, Special Metals, Inc., and Ladish Company. Modeling studies have described deformation and discontinuity migration during extrusion and isothermal forging as part of the effort to validate the selective ultrasonic concept. Udimet 720 powder has been produced and stainless steel canisters have been HIPed and extruded into billets. An exploratory seeding study is underway to define the detectability of inclusions. The final die design for the Stage 3 turbine disk has been defined. Exploratory efforts are being undertaken to optimize machinability and reduce distortion and residual stress. The sec-

ond users group meeting is planned for October 1998 to review project activities and identify other applications for the enhanced P/M technologies.

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PARTICIPATING ORGANIZATIONS:

Allison Engine Company
Ladish Company
National Center for Excellence in Metalworking Technology
Naval Air Systems Command
Naval Air Systems Command
Naval Air Warfare Center - Patuxent River
Special Metals Incorporated

S0883

Title: **Enhanced Processing for High Strength Steel Castings and Forgings for Naval Components**

Start Date: 07/01/1997

End Date: 01/01/2000

Total Activity Funding: $3,630K

Abstract: The objective of this project is to develop manufacturing processes for the cost-effective production of high strength, high toughness steel castings and forgings of nominal 80, 100, and 130 ksi yield strengths with improved resistance to hydrogen-assisted cracking (HAC) and improved weldability.

To reduce weight and improve performance, various high strength steel (e.g., HY-80/100) castings and forgings are used on submarines and surface ships. This project will provide solutions to four manufacturing problems with these high strength steel castings and forgings identified by Naval Sea Systems Command (NAVSEA) :

(1) Hydrogen embrittlement and cracking in HY-100 castings

(2) Excessive hardness and low fracture resistance in HY-80 castings due to improper heat treatment

(3) High fabrication costs due to preheat requirements during welding

(4) Health hazards due to exposure to hexavalent chromium fumes during cutting and welding.

Determination of optimum thermal soaking treatments for mitigating HAC in HY-80/100 will ensure the quality of high strength steel castings and prevent costly rework operations and possible in-service failures.

Identification of casting alloys that are less susceptible to HAC and low fracture toughness due to improper heat treatment should reduce production risk and broaden the supplier base resulting in acquisition savings due to increased competition.

Weld fabrication costs can be reduced by replacement of HY-80/100 castings and forgings with alternate high strength steels requiring reduced or no preheat.

Generation of less hexavalent chromium fumes during welding would reduce the cost of fume extraction.

This project will benefit all Navy combatant and non-combatant ships containing HY-80/100 castings and forgings, primarily submarines but also aircraft carriers, destroyers, assault, auxiliary, and sealift ships.

Technical Approach

A database of optimum thermal soaking conditions for hydrogen removal will be compiled. The time and temperature for sufficient hydrogen removal from HY-80/100 castings will be specified as a function of composition, geometry, initial hydrogen content, and required final hydrogen content. Existing numerical models will be enhanced to improve prediction of residual stresses and hydrogen distribution in castings as a function of geometry, initial hydrogen content in the melt, and processing conditions. Use of these tools will enable probable HAC locations to be determined and could lead to process improvements for reduced or redistributed residual stresses and/or hydrogen levels in castings.

NAVSEA has already certified the substitution of HSLA-80/100 plate materials for HY-80/100 plates for certain applications in ship construction. The evaluation of alternate casting and forging alloys will begin with trials using HSLA-80/100 plate compositions and will include casting / forging characteristics, mechanical properties, weldability, optimization of the heat treatment, and demonstration of minimal sensitivity to HAC. A Ni-Cr-Mo steel developed for 80 ksi yield strength with improved weldability by OGI under a National Shipbuilding Research Program SP-7 project may also be evaluated. In addition to the 80 and 100 ksi yield strength levels, the forgings will also be evaluated at the 130 ksi yield strength level for replacement of AISI 4130 forgings which also require preheat for welding.

The key deliverable for this project will be technical input for NAVSEA certification of alternate casting and forging compositions to replace HY-80/100 castings and HY-80/100 and AISI 4130 forgings for naval ship construction, overhaul, or repair. This will include information on processing, mechanical properties, and weldability of alternate high strength steels, and the demonstration of processing enhancement via fabrication of a representative casting and forging. Analytical and/or numerical tools to minimize hydrogen embrittlement and heat treatment problems with the HY-80/100 castings will also be provided.

This project is well underway. Equipment for hydrogen charging and analysis has been installed. A preliminary computer model has been set up to simulate the residual stress distribution during quenching and thermal soaking. In this model, hydrogen diffusion is represented as a function of temperature only, the next step is to incorporate the effect of stress on the diffusion of hydrogen. Test plans have been outlined for hydrogen charging experiments and evaluation of thermal soaking treatments. A cast test block of HY-100 with unacceptably high hydrogen was procured to evaluate the hydrogen mitigation treatments.

Cast test blocks of the three candidate compositions have been procured. A computer model has been developed to predict the cooling rate required in a 3/4" plate sliced from the test block to simulate cooling of a thick section in a casting. This tool will be used in optimizing the heat treatments for both the cast and forged materials. Thicker plates, also sliced from the test blocks, are being forged.

Evaluation of ASTM A707 grade L5 mod., used for offshore structures, as a replacement for HY-80 forgings was completed. HSLA-100 plate stock was forged into bars and heat treated to 130 ksi yield strength. Evaluation of these bars as a replacement for 4130 tie-down fittings is nearing completion. Reports on both these efforts will be issued in FY99.

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PARTICIPATING ORGANIZATIONS:

National Center for Excellence in Metalworking Technology
Naval Sea Systems Command
Naval Sea Systems Command

A0816

Title: **Optimized Atomization of Magnesium Powder**

Start Date: 05/01/1996

End Date: 12/01/1998

Total Activity Funding: $976K

Abstract: The objective of this project is to increase the manufacturing yield of atomized magnesium powder. By achieving the above objective, the acquisition costs of atomized magnesium powder will be reduced by $3-6 per pound, resulting in yearly savings of $1-2 million. These savings will be distributed over 20 weapon systems including tracers, flares, and IR countermeasures.

This project consists of using both computer-based simulation tools and subscale trials to develop improved nozzle designs which will meet the specifications required to manufacture magnesium powder by gas atomization. A computer-based simulation code will be developed and used to examine various nozzle designs. The most promising designs will be fabricated and examined on a subscale basis. Due to the long atomization runs currently used by industry, test runs of over one hour will also be conducted to ensure compatibility with standard operating practices. Other process variables not related to the nozzle operation will also be examined.

Deliverables/Implementation

(1) a nozzle design capable of over 100 hours of continuous operation

(2) a computer-based numerical analysis tool capable of simulating the atomization of metal powders

(3) a report summarizing the effect of process variables on the production yield of atomized magnesium powder.

Computer based simulation tools have been developed that model the effect of nozzle designs on the atomization gas flow field. Various nozzle designs have been examined and subscale trials have been conducted. Preliminary analysis of powder yields show an increase of up to 75 percent. Final tests on the effect of nozzle designs on powder size are currently underway.

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PARTICIPATING ORGANIZATIONS:

Hart Metals
Institute for Manufacturing and Sustainment Technologies
National Center for Excellence in Metalworking Technology
Naval Air Systems Command
Naval Air Systems Command
Naval Air Warfare Center - Patuxent River

F33615-96-C-5628

Title: **Novel Low Cost Thermosets for Advanced Aerospace Composites**

Start Date: 04/01/1996

End Date: 04/01/1998

Total Activity Funding: $750K

ABSTRACT: Designed from the molecular level, Aspen's novel liquid crystal thermoset system repre-sents the maximum opportunity for significant cost reductions in aerospace quality composite fabrication, and is the leading edge in thermoset design research. This system meets the challenge of high temperature performance with reduced processing costs and increased damage tolerance. Current resin systems can only achieve high temperature performance goals through elevated cure cycling, translating to added costs throughout the manufacturing process and a reduced composite damage tolerance. Aspens novel thermo-set class initiates a close functional group packing density, allowing complete crossing conversion at sub-stantially below the polymers final glass transition temperature. The result is a high temperature, high strength polymer cured at room temperature with enhanced damage tolerance. The Aspen Research and Development Team is comprised of world leading experts in computational molecular modeling, polymer & material science, advanced composites, and aerospace engineering and includes: Dr. Peter Baettcher, retired head of polymer research and new technology acquisition at DuPont; Professor Timothy G. Gutowski, director of the Massachusetts Institute of Technology Laboratory for Manufacturing and Pro-ductivity; Lockheed Martin Tactical Aircraft Systems; and Fiberite, Inc.

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PARTICIPATING ORGANIZATIONS:

Air Force SBIR
Aspen Systems Incorporated

USAMC-98-08

Title: **Physics of Failure for Electronics Equipment**

Start Date: 01/01/1998

End Date: 04/01/1999

Abstract: A complete, integrated manufacturing approach that addresses the impact of manufacturing processes on electronic equipment defects and systems reliability does not currently exist. Existing prac-tices do not provide an in-depth analysis of failure mechanisms and failure sites. In electronic equipment systems, as much as 70% of removals are considered to be attributable to nonassignable causes, making failure detection and maintenance difficult and costly. This project was a joint Service effort to validate the physics of failure reliability prediction methodology using a computer aided design tool. Computer Aided Life Cycle Engineering (CALCE) design software performs vibrational and thermal stress analyses on circuit cards and uses the data in solder joint fatigue and plated-through hole reliability assessment models. This program focused on predicting the reliability of the R/T-1556 control module in the ARC-210 multiservice radio. Accelerated life cycle testing will be conducted to compare the predicted reliabil-ity data with the life cycle testing results to validate the modeling predictions of failure mechanisms, sites, and life expectancy.

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PARTICIPATING ORGANIZATIONS:

Army Manufacturing Technology Program MANTECH
Army Materiel Systems Analysis Activity

HS.04.06

Title: **Knowledge Representation Technologies for Human Performance Enhancement**

Start Date: 10/01/1998

End Date: 09/01/2002

Abstract: Develop a unified and comprehensive knowledge representation technology that supports the acquisition, storage, maintenance, retrieval, and application of digitally coded human knowledge and skill. This DTO will capitalize on cutting-edge cognitive science. The technology will enable (1) efficient methods for knowledge engineering (extraction and coding of human expert knowledge) and knowledge recoding (extraction and recoding of existing, knowledge-bearing digital data) ; (2) authoring tools for knowledge-based (individual and team, local and distal) courseware that capitalizes on these knowledge technologies; (3) tools for planning, deploying, and life-cycle management of courseware over local, wide-area, and global networks; (4) tools for human performance assessment, remediation, and support over local, wide-area, and global networks; (5) tools for rapid deployment of just-in-time and theater-specific training; (6) tools for automated feedback of human performance data to centralized human re-source tracking facilities in order to support ongoing empirical improvement of personnel selection, training, job aiding, and workspace design; and (7) tools for searching, browsing, and otherwise utilizing archived knowledge to support all forms of training, education, and performance enhancement and media.

Payoffs. Maximum payoff will occur through widespread use of this enabling technology and resultant enhancement of enabled technologies at operational performance levels (in the form of job-aiding tech-nologies), at logistical levels (in the form of personnel management technologies), and in the training arena (in the form of advanced courseware and courseware authoring systems). Large-scale implementa-tion of knowledge-based courseware and courseware authoring technologies can significantly reduce the cost of military instruction while simultaneously increasing training effectiveness. Knowledge recoding techniques enable the efficient extraction of knowledge and skill information from existing data sources. Example sources include occupational survey data, technical databases, and legacy courseware. Knowl-edge-based job aiding can increase operational readiness and reduce human errors. Finally, knowledge archiving can eliminate systemic knowledge loss due to the attrition of expert personnel.

Challenges. The greatest challenge in this area derives from converting the DoD training establishment from a behavioral psychology of human performance to a cognitive psychology of human performance. Although the data supporting the power of this new approach is overwhelming, the behavioral approach to human performance is very entrenched in the internal DoD training hierarchies as well as among DoD training contractors. Policy definition and coordination activities must help create a commercial and fed-eral environment that encourages this technology upgrade by providing carefully targeted examples.

MILESTONES/METRICS:

FY1998: Develop and demonstrate a generalized knowledge representation scheme with associated stu-dent modeling module for knowledge-based, intelligent computer-aided instruction (ICAI) application. Begin development of a knowledge-based ICAI authoring system. Initiate migration of existing simula-tion-based ICAI authoring environment to Java for platform independence and Internet compatibility.

FY1999: Complete migration of simulation-based ICAI authoring environment to Java. Demonstrate plat-form independence and Internet compatibility. Initiate development of knowledge-based technologies for automated curriculum planning and media selection.

FY2000: Demonstrate capacity to convert digitized occupational survey data and technical order data to partially populate knowledge bases. Demonstrate 70% reduction in time to develop student models for knowledge-based ICAI courseware.

FY2001: Complete validation of Java version of simulation-based intelligent tutor authoring environment and demonstrate knowledge representation (KR) -based intelligent tutor authoring. Demonstrate 80% reduction in time to develop knowledge-based and simulation-based ICAI that is Internet ready.

PARTICIPATING ORGANIZATIONS:

AETC/XPRT
AFRL-HEJT
DDR&E (E&LS)
Joint Strike Fighter Office
USD (A&T)

IS.12.01

Title: **Simulation Representation**

Start Date: 10/01/1998

End Date: 09/01/2004

Abstract. Enable developers and users of M&S applications to represent the natural environment, the performance and capabilities of warfighting systems, and human behaviors (individual and group) in a manner that promotes cost-effectiveness, ready access, interoperability, re-use, and confidence.

Payoffs. This DTO will enhance the realism of models and simulations used in military training, acquisition, and analysis by providing authoritative representations of (1) static and dynamic, natural, and man-made environments (including weapon effects), and related effects on human and system performance; (2) the performance and capabilities of warfighting systems and their effects on natural and manmade environments; and (3) human behavior (individual and group). Representations of the terrain, ocean, atmosphere, and space require large volumes of diverse authoritative data assimilated and integrated over time and space in order to simultaneously account for large numbers of significant environmental conditions and effects in a consistent and correlated manner over numerous heterogeneous simulations. These efforts will specifically support DARPA's Synthetic Theater of War (STOW) ACTD and Advanced Simulation Technology Thrust (ASTT) programs and joint modeling and simulation system developments like JSIMS, JWARS, JCOS, JLOTS, improved computer-generated forces (CGFs), and C4ISR applications, as well as DoD's battlefield visualization program. Coordination of efforts is essential with the Sensors, Electronics and Battlespace Environment JWCO efforts, ASTT, and the Rapid Terrain Visualization (RTV) and Battlefield Awareness and Data Dissemination ACTDs to ensure operational effectiveness and consistency.

Challenges. Major challenges include rapid database generation and target modeling, near-real-time interaction of consistent and correlated representations, and multiresolution modeling of complex, consistent, and correlated environments. Efficient models, a flexible architecture, and wide-bandwidth communications are needed to provide accurate and believable simulated representation of the battlefield situation at multiple locations for bomb damage assessment and commander's situational awareness. The major technical challenge for the representation of human behavior includes providing variable human behavior for friendly, enemy, and nonhostile personnel. These representations must reflect human capabilities and limitations, cognitive processes, and factors that influence performance such as stress, fatigue, and expe-

rience-to include CGFs that exhibit platform-based as well as statistical-based behavioral modeling, logistical effects, and command forces (CFOR) models through division level.

MILESTONES/METRICS:

FY1998: Test and evaluate the capability to generate an integrated feature/elevation terrain surface for 2,500 km2 area in 72 hr; field the Master Environment Library System to include an air and space models and algorithms catalog; enhance system representations; interface with the environment and human behavior; extend CFOR command entities to battalion level; demonstrate rapid modeling of structures and critical battlefield systems; demonstrate rapid generation of CGF adaptive behaviors; develop tools and technical methods to acquire knowledge and better represent human behavior; complete interchange specification for environmental source data and integrated databases; develop and initiate prototype semi-automated forces architecture for assembling primitive behavioral elements into customized tactical behaviors.

FY1999: Demonstrate capability to generate and interchange integrated, consistent synthetic environments (terrain, oceans, and atmosphere) within 72 hr; demonstrate use of the virtual interactive target to populate the battlespace with targets and use physics-based weapon effects models to calculate weapon-specific damage to them; develop knowledge base reflecting variable human behavior at individual level; extend representations of effects of human C2 decision-making processes in company- and battalion-level surrogates; extend the models and algorithms catalog to all environmental domains.

FY2000: Transition interchange specification for environmental databases to designated office of primary responsibility for configuration management and user support; develop initial capability for timely generation of integrated database for space M&S.

FY2001: Demonstrate capability to generate and interchange integrated, consistent synthetic environments (terrain, oceans, atmosphere, and space) at multiple resolutions within 72 hr; expand human behavior knowledge base to incorporate variable human behavior at organizational unit level and for large-scale logistical effects.

FY2002: Expand knowledge base to incorporate variable human behavior at the enemy and non-hostile force level; initiate capability to apply and manage dynamic changes in multiresolution environments for planning and operational purposes.

FY2003: Develop tools to enable dynamic, scaleable (micro-to-macro) adjustments to the synthetic environmental representations in simulations running in real time; extend representations of C2 decision-making process to brigade, division, and corps surrogate levels.

PARTICIPATING ORGANIZATIONS:

DARPA Information Systems Office
DDR&E (IT)
Defense Modeling and Simulation Office
Defense Special Weapons Agency
Marine Corp (US)
USD (A&T)

IS.11.01

Title: **Simulation Information Technologies**

Start Date: 10/01/1998

End Date: 09/01/2004

Abstract. Provide the services and DoD agencies the technologies and standards necessary to develop simulations that provide consistent, reliable, and credible results.

Payoffs. The properties of a robust end-to-end modeling and simulation (M&S) development process will be established to ensure that operationally valid and consistent simulations are built in compliance with the DoD goals of credibility, reusability, interoperability, and efficiency. Technologies required to support the realization of this process include conceptual models of the mission space (CMMS) -authoritative functional descriptions that serve as the basis for simulation design and implementation; authoritative data sources (ADS) - a defined set of data sources recognized as authoritative; M&S resource repository (MSRR) – a mechanism for easy access to and sharing of simulation and data set information; and an embedded verification, validation, and accreditation (VV&A) process with supporting tools to achieve quality assurance. The VV&A process will focus on the establishment of credibility and mitigation of risk associated with software development. These collective efforts will serve to support DARPA's Synthetic Theater of War (STOW) ACTD and Advanced Simulation Technology Thrust (ASTT) programs and future M&S applications including the Joint Simulation System (JSIMS) and the Joint Warfare Simulation (JWARS).

Challenges. Developing coherent, complete, and consistent simulations is an extensive task. DoD M&S spans a wide range of missions, from conventional warfare to operations other than war. M&S must simulate activities from system acquisition to mission planning, rehearsal, and training.

MILESTONES/METRICS:

FY1998: Prototype CMMS library ready for JSIMS, Warfighters Simulation 2000, National Air Space Model, and JWARS. Produce DoD VV&A recommended practices guide (RPG) with links to VV&A tool set for acceptability definition, fidelity assessment, and validation activities. Complete pilot studies on impacts of security policies; initiate studies of M&S VV&C procedures and guidelines; develop M&S cataloging and registration specification as standard for online resource repositories and MSRR implementation.

FY1999: Prototype version of online CMMS repository including functional descriptions for analysis and training available for engineering and engagement level of detail in acquisition and OT&E-related simulation; produce DoD VV&A/C RPG enhancements to focus on incorporating concepts of risk assessment, decision making, return on investment, and cost metrics. Prototype VV&A tool concepts.

FY2000: At least 50% of major simulation program developers will have contributed to populating CMMS. CMMS library used by warfighter to collect, evaluate, and eventually validate doctrine, functions, tactics, techniques, and procedures. (Techniques for modeling complex data structures initiated in FY96 demonstrated and completed.) Produce VV&A tools.

FY2001: Development of common semantics and syntax and associated data interchange formats (DIFs) for campaign-level representations of environment, units and systems, and operations and human behavior.

FY2002: CMMS will represent DoD activities. Warfighters have worldwide access to conceptual models of DoD processes. Authoritative data will be available for representations of most synthetic environments, portions of units and systems, operations, and human behavior.

FY2003: Development of common semantics and syntax (CSS) and associated DIFs for representations of environment, units and systems, and operations and human behavior for all levels of warfighting incorporating the greater degree of detail and fidelity required.

PARTICIPATING ORGANIZATIONS:

DARPA Information Systems Office
DDR&E (IT)
Defense Modeling and Simulation Office
Marine Corp (US)
USD (A&T)

IS.10.01

Title: **Simulation Interconnection**

Start Date: 10/01/1998

End Date: 09/01/2004

Abstract: (1) Develop an advanced runtime infrastructure (in time, data distribution, and large-scale federation management) to support high-level architecture (HLA) federations. (2) Develop automated tools to support federation development, including automation of the end-to-end process of identifying candidate simulations, developing HLA object models, and planning testing and operating federation events. (3) Investigate innovative techniques for supporting scaleable executing systems using an HLA to include systems other than simulations (e.g., C4I systems). (4) Develop an automated HLA compliance testing capability.

Payoffs. This DTO supports the interoperability and reuse of simulations, and supports or augments applications. The program will provide users the technical standards and infrastructure to connect joint and component simulations, in a composable fashion, to support the functional areas of training and other operations, acquisition, and analysis. The same infrastructure and interfaces can be used for a wide variety of simulation applications. This will allow users of applications to benefit from improvements in infrastructure without having to pay for them or having to upgrade their applications—substantially decreasing time and manpower to support user applications. This critical capability facilitates the use of M&S for enhanced battlefield understanding, integrated force management, and predictive planning (Reference DTOs IS.01.01,.02.01, and.03.01) ; and will augment decision-making processes.

Challenges. The major technical challenges include establishing the architectural design and standards and security approach to facilitate the interoperability of simulations across a broad range of simulations in DoD; developing the supporting infrastructure software to apply the architecture to simulation application with the needed levels of performance; innovatively developing automated tools to make use of the architecture cost effectively; and extending the architecture to provide advanced time management, data distribution, and federation management services.

MILESTONES/METRICS:

FY1998: Design and develop innovative runtime infrastructure software demonstrating increased performance (25% improvement) and broad-based portability (reduce cost of porting by 25%) ; extend HLA services to address user needs, to include live systems (systems other than simulations), for advanced time, data distribution, and federation management (increasing user base by 10%) ; demonstrate technologies to support larger scale federations (10% increase) and compliance testing capability.

FY1999: Develop prototype for initial automated tools to support federation development testing (reducing time to create a new federation by 20%) and advanced system planning and runtime management tools; improve compliance testing capability to support the efficient operation of large-scale applications (20% less manpower).

FY2000: Apply increased advanced integrated automation to federation development and operation, demonstrating additional (20%) reduced costs to create a new federation.

FY2001: Demonstrate runtime infrastructure advances using next-generation software and hardware to increase (20%) performance for the same cost, using commercial software to replace 50% of custom software.

FY2002: Advanced support software will demonstrate prototype version of automation of the end-to-end process of identifying candidate simulations; define runtime data exchange requirements, network and computer resource requirements, configuration testing, operation, and monitoring of federation operation.

FY2003: Application of advanced technology will support actual application of end-to-end automated support to programs using HLA to support applications, demonstrating actual improvements in manpower requirements (25% less) and timing (20%).

PARTICIPATING ORGANIZATIONS:

DARPA Information Systems Office
DDR&E (IT)
Defense Modeling and Simulation Office
NAVMSMO
USD (A&T)

MP.32.01

Title: Fast, **Affordable, Product Realization**

Start Date: 10/01/1998

End Date: 09/01/2002

Abstract: Develop and demonstrate key advanced information technologies, such as simulation and modeling techniques and international product data standards, needed to enable shorter, lower cost transition from design to production and repair.

Payoffs. The goal is to contribute to meeting DoD requirements for sharp reductions in production and repair cost and time through more effective industrial and manufacturing engineering processes that plan, schedule, and control factory operations. These processes are directly responsible for more than one-third of weapon system costs and strongly influence the efficiency of another third. The JSF Program Office has determined that improvements to these above-the-floor functions could reduce production costs by 25%. A secondary goal is to contribute tools needed by the acquisition reform thrust to address cost as an independent variable. Technologies developed, extended, or applied in this DTO are needed by, and applicable to, virtually all weapon systems and other defense products in development, production, and operation as well as replacement-part acquisition and the production of uniforms for new recruits. Initial customers include F–22, JSF, AWACS, Warner-Robins ALC; and USMC, USN, and USAF recruit induction centers. These technologies are required to integrate and improve the many disparate information systems used by individual organizations and their supply chains to analyze designs for manufacturability and to plan, schedule, and control manufacturing and repair facilities. This program also will provide technologies that emphasize affordability analyses to facilitate design for low-cost manufacturing and

rapid transition from design to production. This DTO supports the Force Projection/Dominant Maneuver and Electronic Combat JWCOs.

Challenges. Technical barriers include inability to capture and communicate design intent; inability to simulate the downstream manufacturing cost effects of design decisions; inability to interoperate manufacturing, product, and cost information systems within and among companies; lack of effective tools and of accurate, timely information for scheduling individual factories and supply chains for significant reductions in span time and inventories; lack of manufacturing planning methods capable of automatically and correctly selecting and sequencing lowest cost processes; and inability to adequately plan for unpredictable manufacturing environments.

MILESTONES/METRICS:

FY1998: Reduce development time for mixed signal circuit cards by 25% through simulatable specifications; demonstrate the feasibility of extending the technology and its benefits to the electronic subsystems level; demonstrate a potential 1% life-cycle cost reduction on JSF by integrating advanced process planning and factory cell simulation tools.

FY1999: A 3:1 reduction in cost to develop electronics test program sets; these costs are now typically about $675 million per aircraft program. Transition a distributed design environment for IPPD in missiles and similarly complex electro-mechanical systems.

FY2000: Demonstrate the ability to explore 10X more design alternatives in conceptual design in half the time. Validate STEP (Standard for Exchange of Product) testing suites for shipbuilding applications.

FY2001: Reduce lead time by at least 50% (from 122-day baseline) with commensurate reductions in inventory for items acquired by all USMC, USN, and USAF recruit induction centers by integrating DoD systems for product data, procurement, and ordering with industry systems for factory planning, scheduling, order release, and shop floor tracking.

PARTICIPATING ORGANIZATIONS:

DDR&E (LM/TT)
Joint Strike Fighter Office
USD (A&T)
USMC Training Center

TTO-07

Title: **Simulation-Based Design (SBD)**

Abstract: The Simulation-Based Design (SBD) Program developed and tested a prototype digital knowledge environment for representing physical, mechanical, and operational characteristics of a complex system. Such an environment enables a significant positive change in the acquisition process for large, complex warfighting systems. SBD uses virtual prototypes in synthetic environments to enable effective, integrated product and process development. The program integrates the technologies of distributed interactive simulation, physics-based modeling, and virtual environments and applies them to the design, acquisition, and life cycle support processes of systems.

FY 1997 Accomplishments:

- Conducted interim Simulation-Based Design (SBD) prototype engineering demonstration tests, in conjunction with ongoing acquisition programs of the multi-disciplinary engineering analysis capability supported by the advanced computational core architecture.

- Initiated SBD prototype engineering tests of the smart product model in support of integrated life cycle requirements and analyses of an evolving maritime application.

- Made available SBD prototype software to DoD Service's beta sites and acquisition programs for use, evaluation, and feedback.

FY 1998 Plans: Continue simulation based design and virtual reality efforts, in a collaborative program with private industry, for the Gulf Coast Region Maritime Technology Center.

POINT OF CONTACT: Gary Jones

PARTICIPATING ORGANIZATIONS:

DARPA TTO
Gulf Coast Region Maritime Technology Center

DSO-31

Title: **RaDEO-IGD Overview**

Start Date: 04/01/1996

End Date: 06/01/1998

Abstract: The basic concept of the RaDEO program, titled "Development of an Adaptive Modeling Language for Knowledge-Based Engineering with Application to Interactive Gimbal Design (IGD) ", is the development of an Interactive Gimbal Design System (IGD) that will allow for the efficient integration of overall Gimbal System Requirements, Sensor Models, Optical Designs, Mechanical Designs, Structural Analyses, Stabilization Models and Manufacturing Processes. The IGD system will capture previous successful gimbal designs and have available a database of gimbal sub-components. The IGD System will offer a significant productivity increase the ability to design and evaluate gimbal systems.

The design, analysis, and manufacturing of gimbal and integrated optical systems is a complex, highly interactive, and time-consuming process that contributes significantly to the overall product cost of EO systems. This task must address cost, technical performance, customer/vehicle specification considerations, weight, dynamic performance, accuracy, environment and a host of other aspects in order to bring about an effective design. The multi-disciplinary nature of the design process includes system control engineering, mechanical design, system simulation, structural and thermal analyses, servo electronics and manufacturing processes. Significantly contributing to this design process is the use of off-the-shelf items (bearings, gyros, resolvers, and torquers) whose operational and physical properties, environmental limits and interfacing requirements are fundamental to the design process. Our RaDEO-IGD program is the most extensive effort ever undertaken by the Mechanical Computer Aided Engineering department at Lockheed Martin Electronics & Missile Systems. It will require the integration of software products such as: Pro/E, PATRAN, Master Series, NASTRAN, Matrix-X, ACCOS-V, FEM/SINDA, M-Vision, AVS/Express and AML.

A generic solution to offering a design methodology to this complex problem is offered through the continued development of an Adaptive Modeling Language, AML, a knowledge based language/system offered by TechnoSoft, Inc. AML is an advanced modeling language for Knowledge Based Engineering that can capture the methodology and knowledge associated with design/simulation/manufacturing processes. AML facilitates adapting to changes by automating the design and manufacturing process and provides a unique interactive design environment. AML incorporates a unique underlying object-oriented part model for representing the part geometry, the part material, the part process plans, and the finite element model. The part model can allow for the interaction among the multiple disciplines involved in the

design. An important characteristic of AML and the IGD system will be the ability of the system to capture the knowledge to streamline the gimbal design process, allowing a software structure that permits creativity while simultaneously capturing the knowledge of that creativity.

The development of the IGD system, including the STEP database of gimbal sub-components and the modular, STEP interface of the software applications (where applicable), will offer an order of magnitude increase in the review of feasible gimbal designs offering significant savings in product development time and cost. The complimentary development of the IGD system with the AML language of the knowledge-based system will serve to both confirm and guide this technology and at the same time offer significant cost reductions to DoD programs. The successful development of this knowledge based software to a mature system will reduce cycle times and impact life cycle costs. Concept and validation stages of AM3 can use this system to predict and assess engineering designs and manufacturing processes. Additionally, the JAST program (Affordable Modular EO/IR Sensors, JMCATS, etc.) will directly benefit from this research. The RaDEO system methodology can be applied to JAST to assess high risk, high cost system processes early in the acquisition cycle.

The IGD System complements ARPA and joint service investments in seeker and sensor cost and cycle time reduction. The ARPA Affordable Multi-Missile Manufacturing (AM3) investment at the missile and seeker enterprise level and the ARPA investments at the component level, such as Interferometric Fiber-Optic Gyro (IFOG), Rapid Prototyping of Application Specific Signal Processors (RASSP), and Infrared Focal Plane Array (IRFPA) programs, complement Army MANTECH programs for the Dewar Millimeter Wave (MMW) Transceiver, Electromagnetic Interference (EMI) Screen, and the MMW Cost Reduction Program (CRP) in MMW Electronics, as well as Air Force and Navy efforts in Joint Advanced Strike Technology (JAST).

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PARTICIPATING ORGANIZATIONS:

DARPA Defense Sciences Office
Lockheed Martin Electronics & Missiles
Wright Patterson Research Laboratory

DSO-22

Title: **RaDEO-MIND: Multiphase Integrated Engineering Design**

Abstract: The goal of the MIND project is to develop key enabling technologies and tools to support integrated product design across design phases and disciplines from early stage designs through manufacture for electromechanical products. No unified supporting technology exists to consider whether the early designs are functional and manufacturable, so that time-consuming physical simulations have to be created and executed. MIND's technical innovations will support a highly effective engineering process that will function at geographically distant locations and enable more design alternatives to be evaluated. By extending the concepts of feature-based parametric design to earlier design phases and by integrating multiple domains of design, MIND will accelerate the design and manufacture of complex modern DoD weapons systems while reducing the costs. Sample design projects include electro-optical and electromechanical products, and will include use of catalog components as well as custom designed subassemblies.

Technology Objectives:

- Develop Design Assistants (DAs), or sets of algorithms that facilitate the engineering process by systematically performing design.

- Create Design Area Encapsulations (DEs), or common rules of design for electro-mechanical products.

- Formulate Linked Design Alternatives, or collections of design variations that can be used to explore a design space and to manage a family of closely related products.

- Introduce Early Stage Features and Flexible Elements to facilitate the evolution of a complete integrated representation

MIND's innovations will contribute significantly to the ease, effectiveness, and speed of engineering design by incorporating more of the engineering design process into the CAD system. Design Assistants and Design Area Encapsulations will result in a considerable improvement in productivity and a related reduction in production costs. With the integration of Design Assistants and Linked Design Alternatives into the design process, it will be feasible to consider many more alternatives in half the time now needed to explore a single alternative. Although early-phase design accounts for only 10% of the engineering budget, it determines as much as 80% of the overall project cost. MIND's innovations will make high-level, more abstract early phase features available to small and medium-sized manufacturing operations, thereby increasing the pool of competitive bidders for DoD projects. This is an important factor for decreasing cost and raising quality of acquisition for DoD.

TECHNOLOGY INNOVATIONS

- Fluency for design teams to cross design discipline boundaries

- Multiple levels of abstraction, alternatives, and variants.

- Ability of design teams to communicate

- Ability to use multiple phases (conceptual, functional, early stage, detail) simultaneously with transparency

MIND's development of a design system that will integrate the processes and information of multiple engineering disciplines will contribute to RaDEO's goal of creating the next generation engineering and manufacturing environment. Collaborations with other RaDEO projects insure relevance to the direct program. MIND's design process representation that evolves throughout the product life cycle contributes to RaDEO's objective of creating representation forms within a networked design and manufacturing environment.

Transfer of the tools developed to the commercial marketplace will accelerate adoption and integration of these tools by defense industry contractors.

The MIND results will have potential applications to DoD collaborative, distributed electromechanical product design, including layered prototyping, analysis, and manufacture. The technology will enable early simulation of designs. Programs benefiting could include AM3, SBD, and JAST, or any other program aimed towards customized products in small quantities. The integration of manufacturing process automation, including planning and NC code generation results into this technology enables early assessment of manufacturability by different processes.

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PARTICIPATING ORGANIZATIONS:

DARPA Defense Sciences Office
University of Utah

NCEMT-23

Title: **Optimization of Atomized Magnesium Powder Manufacture**

Abstract: Currently, there is only one free world producer of atomized magnesium which is used in many ammunition items. Some of these items include 120mm tank cartridges, small arms (5.56mm, 7.62mm, 20mm - generally used in tracer rounds) and infrared flares. Because of recent drastic reductions of munitions procurement by DoD, the cost of atomized magnesium has increased to the point where it is over five times the cost of ground magnesium powder. Thus, based on the current requirements of the Navy/DoD, a long term solution to this problem would be to improve the manufacturing technology of atomizing magnesium with a goal of increasing the yield from 22 to 40 percent. If successful, this would:

1. Allow the Navy/DoD to continue to procure the higher quality atomized powder magnesium

2. Allow the producer of magnesium powder to operate at a sufficient level of production to economically produce atomized magnesium powder

3. Reduce the procurement cost to the Navy and DoD.

By achieving the goals of this project, the acquisition costs of atomized magnesium powder will be reduce by $3 to $5 per pound, resulting in yearly savings of $1 to $2 million. These savings will be distributed over twenty weapons systems including tracers, flares, and infrared countermeasures.

This project consists of using both computer based simulation tools and subscale trials to develop improved nozzle designs meeting the specifications required to manufacture magnesium powder by gas atomization. A computer based simulation code will be developed and used to examine various nozzle designs. The most promising designs will be fabricated and examined on a subscale basis. Due to the long atomization runs currently used by industry, full scale runs will also be conducted to ensure compatibility with standard operating practices. In addition, other process variables not related to the nozzle operation will also be examined.

Implementation

1. A nozzle design capable of over 100 hours of continuous operation and increasing the yield of -200 mesh/ +325 mesh magnesium powder.

2. A computer based numerical analysis tool capable of simulating the atomization of metal powders.

3. A report summarizing the effect of process variables on the production yield of atomized magnesium powder.

PARTICIPATING ORGANIZATIONS:

National Center for Excellence in Metalworking Technology

NCEMT-22

Title: **Development of a HIP Modeling System for Large Complex Parts**

Abstract: Hot isostatic pressing (HIP) of powder materials can produce cost-effective, high-quality, high-performance components for Navy and DoD weapon systems. Use of this process has been limited by delays and costs due to the trial-and-error design of suitable containers for the powder. This project has developed a computer modeling tool for the design and process simulation of HIPed P/M parts.

Material behavior models have been developed in laboratory settings. This project enhances and integrates these models into a problem-solving tool, and includes verification of this tool in realistic applica-

tions. This project builds upon other NCEMT powder metallurgy simulation efforts and draws on results from private research facilities.

Upon completion of this project, the system will be used at Crucible Compaction Metals (a supplier to General Dynamics Electric Boat Division) and will be available for other Navy/DoD applications. The project is directed to Navy needs, but should also address the needs of other services and commercial applications.

This project demonstrates how powder metallurgy and process modeling can reduce the acquisition cost and increase the performance of Navy components. By using HIP, rather than casting a 9,000 lb. pump casing for the main seawater system for the New Attack Submarine (NSSN), savings of $1.4 million per ship are expected. The simulation tool developed by this project allows the prediction of distortion during the HIP cycle.

The current trial-and-error HIP process design is very costly. Each iteration of a component can require container tooling modifications in addition to the base costs of producing the actual component. Depending on size and alloy, these costs can be in excess of $750,000. The HIP modeling system will simulate this iterative process, thus eliminating the expense of container development trials. Modeling will reduce non-recurring costs for complex components by eliminating the need to make multiple sub-scale and full-size trial parts to predict distortion. Additional machining and material savings are expected, since the HIPed part can be closer to final shape. The HIP modeling system will significantly reduce the cost and schedule risks associated with the use of HIP P/M parts.

Another benefit will be the reduction in lead times for new components. The current iterative practice can have lead times ranging from six to twenty-four months. The computer modeling time for a given iteration will instead be measured in days or weeks.

The cost savings associated with the use of the HIP modeling system in support of the construction of the NSSN seawater system is anticipated to be roughly $1.4 million per ship, including savings associated with replacement of large castings by HIPed components. Additionally, the new design technique is expected to extend the use of HIP fabrication to components for which it is now impractical. Finally, lower design costs should support the use of HIP Powder Metallurgy (P/M) for small, moderately complex components, such as piping elbows, of which there are more than 100 on the NSSN.

Technical Approach

Hot isostatic pressing (HIP) of powder materials can produce cost-effective, high-quality, and high-performance components. Use of this process has been limited by the risk of delays and costs due to the current trial-and-error design practices for suitable containers. This project will develop a computer-aided modeling tool for the design and simulation of HIPed P/M parts.

In the P/M HIP process, a metallic powder is consolidated by the combined action of pressure and temperature. Among the factors that control shrinkage are the pressure and temperature cycles, non-uniform consolidation of the powder, and temperature variations inside the autoclave. The complex interaction of these factors and the dependence of the thermal and mechanical properties of the powder on both density and temperature precludes shrinkage prediction by simple calculations.

In this project, constitutive equations have been formulated to model the behavior of metal powders during HIP. The model has then been implemented into a finite element program suitable for the analysis of thermomechanical boundary value problems. Extensive materials testing was conducted to verify and calibrate the material model in close collaboration with a component manufacturer. The modeling capabilities will be validated through the manufacture of HIP parts under controlled conditions. Computer-aided design tools have been developed to aid in the creation of finite element models and post-processing of results. These tools will facilitate effective system use by engineers in industry. Training aids will also be developed to facilitate technology insertion.

Implementation

Both a 2D and a 3D version of the HIP process simulation software will be developed and transmitted to the industrial partner to support the manufacture of components such as the main seawater pump casing and other seawater system components for the New Attack Submarine. General Dynamics, Electric Boat Division has produced the technical specifications for these components and Crucible Compaction Metals is responsible for their manufacture.

PARTICIPATING ORGANIZATIONS:

National Center for Excellence in Metalworking Technology

NCEMT-19

Title: **Powder Injection Molding of Turbine Engine Parts**

Abstract: PIM is a cost effective process for complex shape manufacturing metal components that eliminates secondary operations by combining the net shape and mass production features of plastic injection molding and the efficient material utilization of powder metallurgy.

The PIM process begins with a feedstock made of powder metal mixed with a thermoplastic carrier. The feedstock is injected into a mold using plastic injected molding machinery to produce a part with the desired size and shape. After the thermoplastic is removed by chemical or thermal treatment, the part is sintered at elevated temperature to fuse the metal particles creating a structure with mechanical properties that meet or exceed cast and wrought alloys.

Powder metal is mixed with a thermoplastic carrier and injected into a mold to produce a part with the desired size and shape. The thermoplastic is removed from the part by chemical or thermal treatment. The part is sintered at elevated temperature to fuse the metal particles creating a structure with mechanical properties on par with forgings in many cases.

PIM is an established, growing technology and is most widely used for high volume production of small sized parts. PIM has not been used extensively for larger parts due in part to the need for process simulation tools relating to mold design.

The PIM project is related to several other NCEMT efforts. Simulation software developed under the Casting Technology project is the basis for the PIM simulation software. Intelligent processing of materials concepts in the High Temperature Superconductor Technology and Semi-Solid Metalworking projects are also incorporated into the PIM production methodology. The NCEMT is working with industry to implement advanced control technologies in PIM process equipment to improve the quality and performance of the process.

At the end of this project, PIM will be sufficiently developed for application to a wide variety of Navy/DoD needs. The NCEMT has established a technology demonstration facility for use by DoD design engineers and production specialists. Follow-on activities will focus on working with the Navy/DoD design community to recognize and exploit the advantages of PIM technology.

Powder Injection Molding is a manufacturing process used in the fabrication of net- or near-net-shape components with highly controlled microstructures and properties. It can be used in the production of both metallic and non-metallic components.

The majority of the small complex components for airframes, avionics, and propulsion systems, including fasteners, brackets, attachments, and electrical components, are machined from barstock or castings. The extensive machining and resulting material loss lead to excessive acquisition costs.

PIM is a highly economical process for mass production of parts that are difficult to form or machine by conventional methods. The use of the PIM molding processes for the production of Naval weapon system components reduces component weight, increases efficiency, reduces manufacturing defects, and improves cost effectiveness.

For example, PIM is being applied to the manufacture of a vane actuator arm for Allisons T-406 engine used in the V22 Osprey. Each engine uses over 350 of the 17-4 PH stainless steel arms. Being a net shape manufacturing process, PIM offers more than a 50% cost reduction over the current sheet metal stamping which also required forming, brazing, and machining steps. PIM actuator arms alone have the potential to save the U.S. Navy more than $1,800,000 over the V22 Osprey procurement life span. A host of other small complicated-shape components for both defense and commercial turbine engine applications are potential candidates for the cost-effective PIM process.

Cost savings for PIM turbine engine components:

- Vane actuator arm (T406 engine) - $3K/engine ($1.8M total)

- Sidewall nozzle segment (F119 engine) - $3.4K/engine ($15M total).

- PIM also offers design flexibility that affords additional cost savings potential.

The PIM project focuses on three areas. The first area is the implementation of PIM components into Navy jet engines. This consists of the selection of components for which the development of material specifications are determined and verified. Suppliers perform a cost benefits analysis for volume production of the components. Prototype parts are produced, tested to specifications, and substituted for the current forged and machined components.

The second area is the development of engineering design tools reduce tooling cost and improve quality. The design tools are a mold filling simulation code and an expert system for mold cavity design. While there are many variables that control the PIM process, mold filling is critical to component manufacture as problems occurring in this phase are perpetuated throughout the remaining steps of the process. The design of the mold cavity is extremely important since the final size of a component relies heavily on the mold cavity size. During processing, components shrink up to 40% by volume, and errors in the initial mold design require rework.

The third area is the development and implementation of sensors and control strategies into processing equipment to improve the quality of the PIM parts. Improvements provide additional control to the process which improves the consistency and quality of the components to be produced.

Navy vendors and parts manufacturers will use the developed product/process optimization tools to redesign components so that they can be made by the PIM process. Components will be fabricated and tested primarily for uses in Navy jet engines. These initially include the T-406 engine for the V-22 Osprey and the F119 engine for the Joint Strike Fighter.

PARTICIPATING ORGANIZATIONS:

National Center for Excellence in Metalworking Technology

DA359803

Title: **Comprehensive FEA Model for Design Optimization of Protective Masks**

Start Date: 12/01/1997

End Date: 12/01/2000

Abstract: develop graphical and mathematical models of the M40 protective mask, the human face, and the interrelationship between protective mask and face when the mask is worn. Develop predictive techniques for estimating the levels of comfort and protection provided by a mask prior to fabrication of prototypes. Develop techniques that combine the use of state-of-the-art technologies and innovative data collection methods to generate and transform geometric and physical data on protective masks and human headforms into digital data that can be modeled using advanced finite element analysis (FEA) methods stage: applied research and exploratory development.

POINT OF CONTACT: Anand Kasbekar, 919 782-3030

PARTICIPATING ORGANIZATIONS:

Army SBIR
Visual Sciences Inc.

DF122026

Title: **Dynamic Data Acquisition And Implementation**

Start Date: 04/01/1997

End Date: 09/02/2001

Abstract: Develop improved methods for modeling the highly nonlinear aerodynamics of maneuvering military aircraft. Products to be delivered include new testing techniques, a parameter database, and data implementation methods. The payoffs for the air force include more efficient and cost effective flight control law development, more representative flight simulation for flight test preparation and pilot training, and increased flexibility for aircraft designers to exploit dynamic characteristics for enhanced maneuverability. This project will use the recently acquired multi-axis test rig in Wright Laboratory's vertical wind tunnel to conduct tests and obtain aerodynamic data. Several models will be designed, fabricated and tested to evaluate new test techniques and acquire data for the parametric database. New data implementation schemes will be developed and integrated into 6-DOF simulators. Simulation results generated with different data implementation will be compared to flight data to determine the conditions under which each method correctly models vehicle dynamics

POINT OF CONTACT: W.J. Gillard, 937-255-0412

PARTICIPATING ORGANIZATIONS:

U.S. Air Force, Wright Patterson Research Laboratory

DA350049

Title: **Design, Modeling, and Fabrication of a Quasi-Optical Power Combiner Based on the Talbot Effect**

Start Date: 07/01/1998

End Date: 01/01/1999

Abstract: To explore innovative quasi-optical combiner architecture for development of MMIC circuits at millimeter wave frequencies. The quasi-optic power combining technique is one of very few promising techniques to use solid state circuits, with their inherent advantages in reliability, durability, low cost, and small size for circuits producing 10's and 100's of watts directly relevant to C3I and digitized battlefield, surveillance and target acquisition, EW, air defense, and smart munitions programs in the Army. Significant potential impact on the mounted and dismounted battlespace, the battle command, the combat service support, the early entry, lethality, and survivability, and the depth and simultaneous attack operational capabilities for warfighting. to investigate a novel concept to base a quasi-optical combining architecture on the Talbot effect, eliminating the need for lenses or other beam guiding structures

POINT OF CONTACT: T. Tayag, 817-257-7126

PARTICIPATING ORGANIZATIONS:

Defense Research Sciences
Texas Christian University

DN055249

Title: **Autonomous Vision Sensor Systems for Manufacturing**

Start Date: 12/01/1997

End Date: 06/01/2000

Abstract: the objective is to develop a series of automated sensing techniques that can be adapted to specific manufacturing applications. The proposed research seeks to build novel sensors and advanced algorithms for recovery of surface/material properties, object recognition, inspection, tracking, object modeling, and software which will provide intelligent assistance in configuration and linkage of the various sensors and algorithms to address user prescribed tasks in manufacturing. Among the new sensors to be examined are a random-access laser rangefinder. In addition, research in polarization-based sensors will be extended into the IR domain. Active vision in a retina-like, log-polar mapping system will be examined. Automated model acquisition for rapid prototyping and deformable object models will be examined for flexible or changing objects. Systems integration will be targeted for a laptop computer implementation

POINT OF CONTACT: Terrance Boult, 919-458-4061

PARTICIPATING ORGANIZATIONS:

Lehigh University
DoD University Research Initiatives

F30602-01-C-0058

Title: **Collaborative Simulation Technology for C4ISR Systems**

Start Date: 04/10/2001

End Date: 04/10/2003

Total Activity Funding: $677K

Abstract: Trends in the modeling and simulation community are leaning toward the development of simulation sets comprised of diverse sets of component and subcomponent models. Resultant simulations cover a diverse set of simulation paradigms that may differ in timing, resolution, scope, platforms, infrastructures and languages. The existing infrastructures and frameworks are not capable of resolving differences concerning resolution and fidelity found in such diverse simulations. RAM Laboratories' Phase II effort will develop a technology that semi-automates the development of middleware and model wrappers that can be used to resolve fidelity differences between models using mixed resolution modeling (MRM) techniques. This technology will allow for the implementation of MRM interfaces utilizing a wide range of techniques including distribution and equation based techniques to advanced clustering algorithms. Use of this technology will facilitate model re-use by allowing companies to co-simulate models from diverse modeling paradigms without having to rebuild their models, thus allowing commercial companies to take advantage of legacy and third party simulation models that may already exist. The use of these models would result in great savings in terms of model construction, model validation, and model verification.

POINT OF CONTACT: Robert McGraw, (858) 677-9207

PARTICIPATING ORGANIZATIONS:

Air Force SBIR
RAM Laboratories, Inc.

F33615-01-C-1842

Title: **Visual Simulation Objects - An Integrated Took Kit for Modeling and Simulation**

Start Date: 4/23/2001

End Date: 4/23/2003

Total Activity Funding: $750K

Abstract: Visual Simulation Objects (VS0), an innovative approach to collaborative virtual prototyping, can be rapidly commercialized to improve the way new software and hardware products are brought to market. Tightly based on Model Reference Technology developed at the Air Force ESC, it extends that capability, providing a more efficient way of developing and maintaining mission evaluation models. Colored Petri Nets are used to visually design complex, distributed systems in a collaborative environment, allowing the behavior of the prototype design to be evaluated before a physical prototype is built. As a component of the C4ISR tool kit, VSO immediately improves JIMM, and its integration with EADSIM provides a powerful mission simulation capability. It will extend the JCAPS standard by providing both a Design Simulation capability that evaluates distributed-processing systems and a Mission Simulation capability to evaluate campaign-level, military worth models such as STORM. VSO has an immediate and direct application in the commercial world for re-engineering legacy software-hardware systems dating to the early 1970s. Currently, brokerage, financial and health care institutions struggle with outdated hardware and undocumented software that cannot keep up in the 24x7 world of the Internet, and there are no adequate tools available that can aid in the re-design.

POINT OF CONTACT: John Woodring, (904) 276-8296

PARTICIPATING ORGANIZATIONS:

Air Force SBIR
Modasco, Inc.

F33615-01-M-1877

Title: **Reconfigurable Integrated Fault Tolerance for Spaceborne Systems (RIFTSS)**

Start Date: 05/01/2001

End Date: 02/28/2002

Total Activity Funding: $100K

Abstract: Reconfigurable Computing (RC) is a technology in which the behavior of a processing system is changed by altering the hardware, rather than the software. This is achieved though the use of field programmable gate arrays (FPGAs). RC is useful when a high degree of both performance and flexibility is needed, and especially when size, weight, or power constraints preclude use of dedicated components for separate functions. The recent development of high-density, rad-hard FPGAs means that RC now has the potential to be used in spaceborne applications. SFC is currently developing an RC tool suite, called DERC (Development Environment for Reconfigurable Computing), which includes both hardware and software to support development of RC applications. RIFTSS will extend the capabilities of the DERC tools to include extensive support for fault tolerance. The DERC API and logic libraries will be extended to include fault tolerant functions, including configuration scrubbing, redundancy, and voting. The DERC Debug Tool will be modified to allow deliberate fault insertion into a design under test. To address system-level fault tolerance issues, this program will also evaluate several third-party modeling and simulation tools to determine how effectively they can handle the unique situations that will occur in fault tolerant RC. Reconfigurable Computing can provide both increased processing power and increased flexibility to systems that must perform a variety of different functions. This is especially important in systems for which weight, space, or power are at a premium (which make it particularly desirable in spaceborne applications). While RC has great potential, its use to date has been small, partly due to the limited number of development tools available. DERC will help enable greater use of RC technology by providing a comprehensive development system for the RC application developer. DERC includes a highly flexible hardware architecture and a full set of supporting software tools. The DERC hardware architecture is already well suited for fault tolerant designs. RIFTSS will extend the software tools to include support for design and testing of fault tolerant systems. Pre-tested fault tolerant logic functions will allow application developers to concentrate more effort on the functionality of the applications, rather than on fault tolerance. The ability to insert deliberate faults into the design under test will speed the testing process, and support improved reliability of the design.

POINT OF CONTACT: Paul Rudolph, (937) 429-9008

PARTICIPATING ORGANIZATIONS:

Air Force SBIR
SYSTRAN Federal Corporation

F33615-01-M-5300

Title: **Improved Titanium Machining Process**

Start Date: 04/11/2001

End Date: 01/11/2002

Total Activity Funding: $100K

Abstract: While recent advances in high speed machining (HSM) of aluminum materials have successfully achieved significant reductions in cost of aerospace structures, these advances have not been successfully applied to titanium material components. Machining costs are a major cost driver in these components, so a meaningful increase in metal removal rate capability will have a significant economic benefit. Primary barriers to achieve high metal removal rates of titanium include:

1) the lack of validated analytical development tools to reduce the dependency on testing trial and error methods

2) the high cost and inefficient methods for testing new machining concepts

3) the inherently different machining characteristics (i.e. material characteristics and behavior during machining) of titanium

4) the high cost of titanium material itself.

The focus of this project will be to develop and demonstrate the application of new and existing modeling technology to cost efficiently reduce the first 3 of 4 barriers identified above. This will be accomplished by:

1) the use of validated software modeling technology specifically developed for modeling metal cutting, (the same baseline technology which was instrumental in HSM of Al)

2) the use of modeling techniques to significantly reduce the need (and cost) for testing while increasing the efficiency and successful implementation of new concepts

3) the use of validated titanium material modeling technology already developed specifically for machining applications.

The benefits to be received are:

1) The immediate commercial availability of a validated software modeling platform for the analysis and development of titanium cutting processes

2) An easy-to-use modeling environment that can be used for both process modeling and cutting tool development

3) The development of a new validated analytical tool that will significantly reduce the amount of testing trials (and hence, schedule and cost) for developing new cutting methodologies

4) A more fundamental scientific understanding of the titanium cutting process

5) A tool that will provide an affordable research method for analyzing, developing, and evaluating HSM techniques specifically for titanium materials

6) Reduced risk and higher success rates for actual cutting tests that are conducted.

Commercial applications include in the broadest sense all machining of titanium components and could very easily be extended into nickel alloy materials as well. Specifically for the scope of this project, Ti-6Al-4V will be the material of choice. The primary application is its' use in aerospace structural and engine components, both commercial and military.

Specific applications will include:

1) Turning machining processes, including boring, reaming, inside diameter and outside

2) Milling machining processes, including end milling, pocket milling, etc.

3) Cutting tool development; geometries, substrates, use of coatings, development of operating specifications, etc.

As example, a typical aerospace engine component may cost $150,000 - $250,000 by the time all the machining is performed. Relatively small productivity increases of 10% - 20% in parts of this high cost return large economic benefits. Multiplied by several hundred units per year, this easily begins to return millions of dollars in savings for just one component.

Likewise the successful application of HSM techniques in titanium may allow HSM to economically replace other less desirable methods such as chemical etching. This could potentially reduce process costs on these same type of components by 50% or more, while also eliminating a hazardous, non-desirable type of process.

We believe the applications and potential for economic return is well known by the industry. However, industry lacks the appropriate tools, capability, and fundamental scientific understanding to be able to economically develop and implement the next higher order level of capability. Instead choosing to rely on present techniques that mainly are past experience and trial and error testing methods.

POINT OF CONTACT: Dr. Troy Marusich, (952) 832-5515

PARTICIPATING ORGANIZATIONS:

Air Force SBIR
Third Wave Systems, Inc.

DAAD17-02-C-0007

Title: **Electromagnetic Modeling of Complex Structures**

Start Date: 11/08/2001

End Date: 11/08/2003

Total Activity Funding: $728K

Abstract: This work will design, develop, and implement a system level electromagnetic simulation framework that increases the productivity of all participants in an EM analysis of a complex system by providing a collaborative engineering environment in which the participants easily construct simulation models, share and re-use data, create computational capabilities that utilize a suite of EM modeling tools, and produce engineering results from the electromagnetic simulation outputs. The heart of the Framework is a rule-based, whole-object conversion process that takes CAD geometry and material data and transforms it into valid, electromagnetic geometry and material modeling components. The CAD converter creates a parametric model, which the user manipulates by varying embedded parameters. When the model is correct, a rule-based gridding approach is used to create a valid EM input for the desired computer code, such as GEMACS, NEC, XPATCH, EIGER, or VOLMAX. The overall Framework provides components for database/library, modeling rules, a "model builder," and "application builder," and a visualizer, in addition to the CAD-to-EM converter.

POINT OF CONTACT: Dr. Edgar Coffey, (505) 897-4741

PARTICIPATING ORGANIZATIONS:

Army SBIR
Advanced Electromagnetics

DAAH10-01-C-0017

Title: **Wing-Store Unmanned Aerial Vehicle**

Start Date: 01/09/2001

End Date: 12/09/2001

Total Activity Funding: $120K

Abstract: A wing-store unmanned aerial vehicle (UAV) is presented deployed from widely fielded existing weapons launchers. Computational simulation and modeling of the UAV as it is launched from a helicopter in hover, forward and sideward (crosswind condition) flight is considered. Comparison of simulation with data from a company 100% scale model test flown previously demonstrates accurate results of simulation. The present effort is directed at the preliminary design of the wing-store UAV for use as a "Bird Dog" off aircraft sensor provider. The pre-design UAV will be modeled and a computer simulation of the launch envelope with a helicopter downwash flow field will be conducted. A "Concept Demonstrator" UAV will be built and test flown from a test stand and from an aircraft during the proposed effort. Off aircraft sensor providers such as a "Bird Dog" UAV would have significant benefits to warfighter and commercial aviation users. Law enforcement, search and rescue, and resource managers would benefit from the application of this technology.

POINT OF CONTACT: Douglas T. Thorpe, (480) 969-2021

PARTICIPATING ORGANIZATIONS:

Army SBIR
Thorpe SEEOP

N00014-01-C-0289

Title: **Technology for Shipbuilding Affordability**

Start Date: 04/02/2001

End Date: 01/31/2003

Total Activity Funding: $750K

 Abstract: The objective of this study has been to demonstrate that the Dimensional Management System (DMS) can be successfully used within the shipbuilding industry. The purpose of dimensional management is to improve quality and reduce rework and the overall cost of ship production. By using computer simulation, the time required to generate and interpret geometric dimensioning and tolerancing scheme will be greatly reduced; the design intent of tolerance controls will be clearly communicated to the Design / Quality / Engineering / Fabrication groups resulting in greatly reduced rework and improved quality and production efficiency.

The present capabilities of DCS's dimensional simulation tools are completely applicable and operational within the shipbuilding domain. These tools were used to model and analyze the assembly of a ship's double bottom blocks, and to model weld shrinkage and distortion, the principal sources of dimensional variation in shipbuilding. The potential applicability of DCS dimensional variation modeling, simulation,

and analysis processes and tools is already very high within the shipbuilding industry. However, during Phase II the improvement of dimensional variation modeling capabilities associated with weld shrinkage and distortion modeling, the refinement of dimensional management processes to suit the industry, and the involvement of U.S. shipyards in the development and evaluation of these processes and tools, will greatly improve the potential applicability of dimensional management practices within the shipbuilding industry.

POINT OF CONTACT: Ramesh Kumar, (248) 786-0145

PARTICIPATING ORGANIZATIONS:

Navy SBIR
Dimensional Control Systems

N00014-01-C-0288

Title: **Technology for Shipbuilding Affordability**

Start Date: 04/02/2001

End Date: 03/30/2003

Total Activity Funding: $750K

Abstract: In Phase II, Vexcel Corporation proposes to adapt and expand its existing close range photo-grammetric process to the unique applications of shipbuilding construction. The enhancements examined in the feasibility study of Phase I will be added to the FotoG system to create new prototype software of particular interest to shipbuilders. This technology will have immediate benefits in the MARITECH ASE major initiative areas of Shipyard Production, Systems Technologies (simulation), and Facilities and Tooling. The process (using randomly acquired handheld photography) allows for highly accurate 3D measurements and 3D models (scene reconstruction) to be extracted from digital photography with no field targeting of points of interest. High accuracy (and automated element extraction) is obtained through the integration of extensive image processing capabilities. Technical objectives for Phase II include supporting the common shipbuilding applications of Run-To-Suit Pipe Modeling, Construction Verification, and Dimensional Control Feedback. Also, (optionally) supporting the CATIA CAD system and the generation of triangulated surface nets.

POINT OF CONTACT: Robert Ledner, (303) 583-0214

PARTICIPATING ORGANIZATIONS:

Navy SBIR
Vexcel Corporation

M67854-01-C-1062

Title: **Ceramic Composite Lined Metal Composite Gun Barrels for Small Arms**

Start Date: 03/19/2001

End Date: 12/14/2001

Total Activity Funding: $70K

Abstract: Rapid fire small arms gun performance is limited by wear and erosion in the chromium plated steel gun barrels which are also heavy for infantry use. Ceramic lined steel gun barrels have demonstrated potential to eliminate the wear and erosion but have failure from cracking for lack of toughness, uniform triaxial restraint and offer negligible weight savings. Recent developments in ceramic matrix composites (CMCs) have the potential to overcome the toughness and cracking limitations of monolithic ceramics. CMC liners coupled with outer shells of metal matrix composites (MMCs) have the potential to eliminate wear and erosion, and achieve up to 50% weight savings over chromium plated steel barrels. This program will demonstrate the fabrication of very high thermal conductivity and toughness CMCs that are functionally graded into MMCs to produce a small arms rapid fire barrel which eliminates wear and erosion, and provides 50% weight savings. Modeling and simulation will be conducted concurrent with CMC composition and fabrication processing demonstration, and screen tested using vented bomb, barrel burst test and thermal conductivity. Selected processing will be utilized to fabricate select CMC composition(s) into barrels including attachments, which will be live fire tested. Ceramic composite lined metal composite tubes not only have a substantial market for all gun barrel applications in DoD, law enforcement and recreational, but such composites have a plethora of applications in engines, brakes and chemical processing industries.

POINT OF CONTACT: Dr. J.C. Withers, (520) 574-1980

PARTICIPATING ORGANIZATIONS:

Navy SBIR
Materials and Electrochemical Research

3.0 Overview of National Science Foundation Grants Related to Modeling & Simulation for Manufacturing

8943166

Title: **Engineering Research Center for Compound Semiconductor Microelectronics**

Start Date: 05/01/1989

End Date: 04/01/1998

Total Activity Funding: $10,541K

Abstract: The Engineering Research Center for Compound Semiconductor Microelectronics has the goal of developing new concepts, materials, devices and systems that would contribute to the elimination of the interconnection bottlenecks that are limiting the performance of high speed digital systems. The demands for increasing the performance of the interconnects and the development of efficient very low threshold semiconductor lasers and hi-speed GaAs based electronics combine to make the examination of optical interconnects for digital integrated circuits very promising. To fully utilize optical interconnects it will be necessary to combine high performance optical and electrical heterostructure devices in integrated devices. The vision of the ERC is to develop the engineering science base which will be needed to realize products based on compound semiconductor optoelectronic chips. Research of this type spans a wide range of topics--from fundamental studies on growth of the semiconductor materials, to device physics, device design, chip- level system simulation and test. The Research Program at the Illinois ERC has four thrusts which together should have a significant impact on the development of optoelectronic integrated circuits (OEIC). These research thrusts are optical waveguides; optical transmitters; optical receivers; systems design and support services. The ERC has been actively involved in impurity induced disordering which it has exploited for laser structures and for guiding light around bends. A SPICE-like simulator for optoelectronic circuits (iSMILE) has been developed along with a laser CAD tool called MINILASE. These simulation tools will help in the design of OEIC's and eliminate the need for actually fabricating some experimental circuits. The center emphasizes educational activities to develop engineering capability in this field.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Engineering Education Centers
University of Illinois

9696212

Title: **ERC for Simulator-Based Manufacturing Education and Training for Microelectronics Processing**

Start Date: 08/01/1996

End Date: 08/01/1998

Total Activity Funding: $529K

Abstract: The goal of this project is to develop, demonstrate, assess, and refine a new approach to manufacturing education and training which promises to enhance the effectiveness of the manufacturing workforce across a broad range of technical expertise. The heart of the effort is a computer-based dynamic simulation and visualization of the time-dependent behavior of chemical processes and associated equipment used to execute these processes in microelectronics manufacturing. The simulations will begin with design, optimization, and control in the area of semiconductor manufacturing, and will then validate the elements that represent the physical and chemical behavior of semiconductor manufacturing equipment and processes. The program includes simulator development and integration, manufacturing training modules, engineering design modules, and assessment and dissemination. The long term goals are to provide a range of simulations that can be used for training industrial technicians, graduate engineers, and graduate students in the operation of the equipment being used in electronics manufacturing, and to allow research and development of new and/or improved manufacturing equipment.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Engineering Education Centers
University of Maryland

9876674

Title: **Center for Environmentally Responsible Solvents and Processes**

Start Date: 11/01/1999

End Date: 10/01/2004

Total Activity Funding: $17,979K

Abstract: The Science and Technology Center for Environmentally Responsible Carbon Dioxide Processes, directed by Joseph M. DeSimone, University of North Carolina, and Ruben G. Carbonell, North Carolina State University, supports a multidisciplinary research program to establish the fundamental understanding necessary to enable liquid and supercritical carbon dioxide (CO_2) to replace aqueous and organic solvents in a large number of key manufacturing and service processes. The Center also supports a range of educational activities including a novel program for undergraduate and graduate students in collaboration and innovation process skills and the development of K-12 education modules.

The Center is organized around four research thrust areas: interfacial and colloid science in compressible media; molecular thermodynamics and computer simulations; rate and transport processes; and chemistry and catalysis. Emphasis will be placed on development of an understanding of surface and interfacial phenomena involving liquid and supercritical CO_2 with the goal of designing surfactants compatible with CO_2, constructing theoretical intermolecular potentials to permit simulation of processes in CO_2-based

systems, understanding the kinetic, transport and rheological properties in these systems, and designing efficient chemical reaction pathways and chemical processes involving CO_2 as a solvent.

The Center is expected to have a significant impact on the development of environmentally benign CO_2 as a solvent to replace aqueous and organic solvents in such industrially important processes as polymer synthesis, spin coating of thin films, textile dying, cleaning, and degreasing. The 39-member team of investigators includes 10 faculty at the University of North Carolina, 13 at North Carolina State University, 5 at the University of Texas, Austin, 5 at North Carolina Agricultural and Technical University (an historically black university) and one at the University of Venice (Italy). Five researchers from National Laboratories (Oak Ridge, PNNL, Los Alamos) will also participate. Technology transfer to industry will occur via interaction with the 16 industrial partners of the existing UNC/NCSU Kenan Center for the Utilization of CO_2 in Manufacturing and the thirty partners of the Separations Research Program at UT-Austin. Approximately 13 postdoctoral associates, 31 graduate students, and 19 undergraduates will participate each year.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Mathematical & Physical Sciences
University of North Carolina - Chapel Hill

9696212

Title: **Engineering Research Center for Net Shape Manufacturing**

Start Date: 05/01/1989

End Date: 04/01/1998

Total Activity Funding: $15,600K

Abstract: The focus of the Engineering Research Center for Net Shape Manufacturing at Ohio State University is on cost-effective net- shape manufacturing of discrete parts. Net shape manufacturing intends to produce discrete parts to finish dimensions so that little or no machining is required prior to assembly. The integration and optimization of product and process design offer great opportunities for savings in time, cost, and resources. Moreover, net-shape productions (molding, forging, sheet forming, casting) are major economic forms of production, and advances in these technologies will make an important contribution to national competitiveness. The goals of the Center are to develop manufacturing knowledge and design tools and people trained in net shape design and manufacturing. The strategic plan of the center is to create an integrated design system offering a choice of materials, metals or plastics, and manufacturing processes in the design and production of net-shape parts. There are four principal thrust areas: billet forming, sheet forming, processing of polymers and composites, and precision and die casting. However, the strategy has been refined both as to the concepts and timing for integration. Knowledge produced in these areas will be integrated as data bases and simulation tools on (1) the behavior of materials, (2) interface phenomena, (3) mechanics of shape change, and (4) characterizations of tooling and machines. Over the next five years, the Center will create a prototype integrated design system for net shape manufacturing, utilizing that data and simulations. The Engineering School has established a graduate program in Manufacturing and Systems Engineering, of which the Center Director is also the Program Director. The Center is a key element in the Engineering School's building up of manufacturing education and research at Ohio State University. The Center has also been innovative in creating a special industrially-sponsored fellowship program to encourage students with U.S. nationality into manufacturing. The Center has es-

tablished a strong working relationship with industrial firms, obtaining the sponsorship of 45 firms, from large to small, including support from the Society of Die Casting Engineers.

PARTICIPATING ORGANIZATIONS:

DOE Office of Energy Efficiency and Renewable Energy
National Science Foundation
Ohio State University Research Foundation

9402533

Title: **Engineering Research Center for Collaborative Manufacturing**

Start Date: 10/01/1994

End Date: 09/01/1999

Total Activity Funding: $10,191K

Abstract: This award supports Purdue University's ERC on the "Collaborative Manufacturing" system. The activities include 1.) integrated product and process development with customer's supplier chain, 2.) flexible manufacturing distributed over networks of cooperating facilities, 3.) teamwork among geographically and organizationally distributed organizational units, which may be highly diverse in size, capabilities, and culture, and 4.) use of high-technology support for collaboration, including high-speed information networks and integration methodology. The central focus of the proposed research is the investigation of fundamental engineering principles that are critical to the success of collaborative manufacturing or test the limits of the concept in case of the most demanding requirements. The ultimate goal is to create the enabling tools and help manufacturing companies and students learn how to make effective use of the new opportunities. There are three major thrusts for the new proposal: 1.) Coherent Product Realization which deals with the issues related to bringing new products into production, supported by the previously- developed technologies in distributed concurrent engineering, performance evaluation design, and product and process simulation; 2.) Coherent Process Integration which relates to analysis and synthesis tools required for integrating all of the activities associated with production; and 3.) Coherent Production System Tools which targets the issues at a system level such as modeling of collaborative production system, decision support structures, and distributed implementation. This award provides support for the ERC for 5 years. In addition, a supplementary award with funds provided by the Army Redstone Missile Command to fund a research project to adapt, extend, and apply research in rapid product manufacturing techniques demonstrated by the Purdue Engineering Research Center (ERC's) Qui ck Turnaround Cell (QTC) system and to support a testbed installation at the Army Redstone Missile Command Production Engineering Division for the purpose of validation and technology transfer. The major thrust for this project is to implement the developed research tools for designing and planning of cylindrical parts. The newly developed design tools will be installed and tested at Army Redstone Missile Command. This system contains new features developed to represent cylindrical and hybrid parts for turning and milling operations. In addition, the interface module will be installed and implemented to validate the simulation results.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Engineering Education Centers
Purdue University

9402723

Title: **Engineering Research Center for Low Cost Electronic Packaging**

Start Date: 11/01/1994

End Date: 10/01/1999

Total Activity Funding: $9,946K

Abstract: This award establishes a new Engineering Research Center (ERC) at the Georgia Institute of Technology on Low-Cost Electronic Packaging. The vision of the ERC is to improve performance of electronic products significantly while simultaneously reducing size and cost. The objectives of the ERC are: (1) to carry-out research, development and prototype manufacturing in low-cost, high-performance, and portable electronic packages consistent with industry needs, (2) to transfer this knowledge to industry, and (3) to train future leaders by educating students, industrial personnel, and faculty from Georgia Institute of Technology and other institutions. The essential components of the ERC are research, partnerships with industry, education, and technology transfer. The research thrusts include: (1) package design and modeling, (2) low-cost micro-chip module (MCM) based on novel materials, processing, and large area planarization, (3) MCMs with integrated passive and active devices, (4) MCMs with integrated optoelectronic components, (5) novel interconnect materials and processing tools, (6) assembly, (7) testing including built-in self test for mixed-signal designs and fault location. (8) thermal management, and (9) large-area prototype manufacturing. The electronics industry is built on the following technology elements: semiconductor chips, electronic packages, power sources, displays, and the systems that are formed through integration. The United States leads in the design of computers, telecommunication system, and the use of electronics in most industrial and commercial applications. The United States trails in consumer electronics, and is increasingly dependent on non-domestic sources for electronic packages and production equipment. Electronic packaging is one of the most important strategic technologies in electronics. The ERC will have a major impact on education of students in this important topic. The Georgia Institute of Technology is among the largest producers of electrical, mechanical, and industrial engineering students in the United States. This ERC will expose undergraduate, graduate and post- graduate students to this area of high national economic importance. This award initiates the ERC with a 5-year cooperative agreement.

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PARTICIPATING ORGANIZATIONS:

Georgia Institute of Technology - Research Corporation
NSF Division of Engineering Education Centers (US National Science Foundation - NSF EEC)

9908052

Title: **Connectivity Proposal: ERC for Computational Field Simulation at Mississippi State and Computational Combustion Laboratory at Georgia Tech**

Start Date: 10/15/1999

End Date: 09/30/2001

Total Activity Funding: $375K

Abstract: This award provides funding for a two-year collaborative project between the NSF Engineering Research Center (ERC) at Mississippi State University on Computational Field Simulation and the Computational Combustion Laboratory at the Georgia Institute of Technology. This project will develop

state-of-the-art large-eddy simulation (LES) techniques for non-equilibrium, reactive fluid flows, implement these models into a state-of-the-art computer code being developed at the ERC, validate the physical accuracy of the resulting simulations by comparison with benchmark calculations and experimental data, and visualize the physics and processes involved. This effort brings together expertise developed at the ERC in high-performance computing and numerical techniques for reactive flows with the knowledge developed at Georgia Tech in turbulence modeling, large-eddy simulation, and combustion simulation. The LES capabilities will be added in a computationally efficient manner with the Loci framework being developed at the ERC. Loci is a C++ library that implements a specification system for the development of unstructured numerical applications.

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PARTICIPATING ORGANIZATIONS:

Mississippi State University
Georgia Institute of Technology - Research Corporation
NSF Division of Engineering Education Centers

9529125

Title: **Engineering Research Center for Reconfigurable Machining Systems**

Start Date: 08/01/1996

End Date: 07/01/2001

Total Activity Funding: $6,908K

Abstract: This award is to support the establishment of an Engineering Research Center on Reconfigurable Machining Systems at the University of Michigan under a new five-year cooperative agreement. The proposed ERC is to help the United States respond to the global challenges in manufacturing by establishing a base of strong fundamental engineering knowledge in reconfigurable machining systems for flexible manufacturing technology. The distinct feature of the proposed Center is to focus on fundamental engineering issues, such as modularity, customization, convertibility, integrability, and diagnosability in reconfigurable machining system. The vision will be fulfilled by improved engineering knowledge and methodologies in stream-of-variation theory, system reliability theory, and open-architecture principles. A testbed will be developed to demonstrate the systems challenges of reconfigurable machining systems. The research is organized into five thrust areas: Thrust 1 on system design & integration with focused research activities on stream-of-variation theory in relation to economics, reliability, integration, and diagnosability; Thrust II on software architecture with focused research activities on open-architecture principles in relation to software reconfigurability and salability; Thrust III on measurement and control with focused research activities on sensors development and modular motion control system; Theory IV on mechanical design with focused research activities on reconfigurable design theory in relation to components, machines, and systems; and Thrust V on processes and tooling with focused research activities on various tooling systems for machining, boring, and drilling, and their process models. The education programs of the ERC will involve undergraduates and graduates in research teams involving industry. The ERC will enhance the industrial exposure to students enrolled in the new practice-oriented M.S. and Ph.D manufacturing degree programs. The ERC will provide curricular modules which will be developed and tested in partnership with the Greenfield Engineering Education Coalition. This vision is enthusiastically endorsed by 32 companies in the automotive industry, the machine tool industry, and the aerospace industry. The research team includes 25 researchers from three UM engineering departments and the UM Business School. In addition, researchers from four universities, including Wayne State University,

Michigan Technological University, University of Illinois, and UC-San Diego will be involved in the research activities within the Center.

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PARTICIPATING ORGANIZATIONS

Michigan Technological University
NSF Division of Engineering Education Centers
University of California - San Diego
University of Illinois
University of Michigan
Wayne State University

0125414

Title: **Innovation in Aircraft Manufacturing through System-wide Virtual Reality Models and Curriculum Integration**

Start Date: 01/01/2002

End Date: 01/31/2005

Total Activity Funding: $598K

Abstract: This award is to Wichita State University to support the activity described below for 36 months. The proposal was submitted in response to the Partnerships for Innovation Program Solicitation (NSF 0179). Proposed Activities: The broad objectives of the project include: foment the use of integrated virtual reality models of manufacturing systems by the partners to design, improve, and operate the manufacturing systems, and teach the workforce (new graduates as well as current industry personnel). The following activities support these objectives: integrate the curricula of the industrial engineering and manufacturing engineering programs at Wichita State University using the model that ties the courses together and integrates the applicability of and interrelation between the knowledge and skills gained, provide the students with real-world experience in manufacturing systems, and transfer the computer modeling tools to industry.

Proposed Innovation: The partnership will provide industry with computer modeling tools that are more realistic and system-based for aircraft manufacturing. The new curriculum will provide students with state-of-the-art real world engineering experience that is closer to the needs of the regional aircraft industry.

Potential Economic Impact: Wichita is home to major manufacturing facilities of Boeing Aircraft Company, Bombardier/Learjet, Cessna Aircraft Company, and Raytheon Aircraft Company. Aviation is responsible for 10% of the earnings in the State of Kansas, and manufacturing is responsible for 60% of the income in Wichita. Since aircraft manufacturers face stiff global competition, innovation is necessary to maintain economic and technological superiority in the aviation manufacturing business. Having state-of-the-art tools and a workforce educated and trained with these tools is absolutely required for survival in this industry sector.

Potential Societal Impact: Economic well being and jobs for this region are critically dependent upon the aviation industry's maintaining its competitive advantage with tools and people trained to use them.

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PARTICIPATING ORGANIZATIONS:

NSF Directorate of Education and Human Resources
Wichita State University
Boeing Aircraft Company
Cessna Aircraft Company, Raytheon Aircraft Company
Brittain Machine Inc.
Delmia Corporation
Kansas Technology Enterprise Corporation
Society of Manufacturing Engineers

0134583

Title: **CAREER: Laser-Assisted Layered Manufacturing of 3D Mesoscale Structures With Embedded Micro Sensors and Actuators**

Start Date: 06/01/2002

End Date: 05/31/2007

Total Activity Funding: $375K

Abstract: The goal of this Faculty Early Career Development (CAREER) award is to integrate research activities with educational efforts in two interdisciplinary fields: layered manufacturing and smart materials and structures. Currently, little has been reported on integrating these two fields, especially at the mesoscale (100 mm to 10 mm). In addition, fundamental issues for mesoscale layered manufacturing processes have not been well defined or investigated.

This program involves research on mesoscale layered manufacturing of smart structures with a special focus on thermomechanical issues at the mesoscale. The approach is to integrate laser-assisted Shape Deposition Manufacturing (SDM) and Laser Direct Write to build, at the mesoscale, geometrically, compositionally, and functionally complex smart structures containing embedded micro sensors and actuators. Analytical models, numerical simulation, and embedded micro sensors will be used to investigate the thermomechanical phenomena. The educational plan is to improve the existing curriculum in the arena of manufacturing by developing new interdisciplinary elements that integrate the fields of layered manufacturing, micro-manufacturing, and smart materials and structures. Additionally, there will be substantial effort to mentor undergraduate and graduate students, and to expose K-12 students, teachers, and industries to novel manufacturing processes and smart devices.

Strategies will be explored to attract, retain, and engage students from under-represented groups (women and especially students with disabilities) to manufacturing fields. The research program will have significant implications for industry in that mesoscale smart devices could become technologically and economically feasible for numerous applications. Emphasis on interdisciplinary materials, hands-on experience, teamwork, and high quality teaching and learning will better engineering education for next generation engineers.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Design, Manufacturing & Industrial Innovation
University of Wisconsin Madison

0114598

Title: **GOALI: Principle-Based Knowledge Management System for Cellular Manufacturing**

Start Date: 10/01/2001

End Date: 08/31/2004

Total Activity Funding: $360K

Abstract: This research project has two thrusts. First, the research aims to develop a set of benchmarking and diagnostic modes based on queuing, material flow, and stochastic optimization models for generic manufacturing cells. These will be used to evaluate the current performance of a system relative to both external (industry) and internal (theoretical) standards. Second, the research will use models to classify improvement areas into broad categories and use these to develop a fundamentally new framework for organizing experiential information related to the design and improvement of cellular production systems. The ultimate goal is to create a prototype web-based knowledge management tool that will diagnose problems, suggest improvement options, and accumulate and classify information for future shared use by the organization. In theory, modern information technology makes it possible to place information previously available only to experts in the hands of users throughout the firm. But converting data to useful information presumes an ability to capture, organize, and link knowledge to the practical concerns of decision-makers. Evolving methods of artificial intelligence provide exciting new ways to search and retrieve text-based information, based largely on matching documents to user interests on the basis of keywords. However, such an approach is not entirely suited to many production environments because users do not necessarily know what keywords they should be interested in to find help with their problems. What is needed is a more proactive system for diagnosing problems and leading users to relevant information.

The need for knowledge creation and sharing systems is becoming even more crucial as manufacturing systems emphasize highly customized products and quick response to customer demands. Agile manufacturing relies on production in small scale, often modular, flexible manufacturing cells that use multi-functional machinery and cross-trained workers. While there has been some recent modeling research into the design and control of agile manufacturing systems, almost nothing has been done on linking models to the information needs of managers trying to evaluate and improve their systems. This research will develop models of cellular systems and use them to establish a framework for organizing information in a knowledge management system to support the process of continual improvement in agile manufacturing systems.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Design, Manufacturing & Industrial Innovation
Northwestern University

0010118

Title: **GOALI/Collaborative Research: Scheduling Methodologies for Electronics and Hardware Manufacturing**

Start Date: 07/01/2001

End Date: 06/30/2003

Total Activity Funding: $205.4K

Abstract: This Grant Opportunities for Academic Liaison with Industry (GOALI) award supports the development of a framework, comprised of models and efficient solution algorithms, for two different problem domains. One that is characterized as multi-stage, sequence-dependent group scheduling problem with carry-over setups, and the other with no carry-over setups. Applications of the former exist in printed circuit board (PCB) assembly, while the latter is applicable in hardware (discrete parts) manufacturing such as those supported by cellular manufacturing. The emphasis is on the development of scheduling models that truly reflect real operational constraints. In a two-stage PCB assembly process, these include performing the setup required on either stage based on a surrogate board group representing all board types, and performing the setup on the second stage in anticipation of the arriving board group. The impact of carry-over sequence dependency is assessed by recognizing that the setup time required of a surrogate board group on either stage is dependent upon the entire set of preceding surrogate board groups that have so far been processed. A variety of performance measures including the minimization of total completion time, mean flow time, and weighted tardiness will be considered in order for the producer to be highly responsive to a variety of customer needs. Recognizing that both problems belong to a class of notoriously difficult 'NP-hard' combinatorial optimization problems, the structure of the problems will be exploited to develop efficient lower bounds. For the minimization of mean flow time, special cases will be investigated to identify those that can be optimally solved in polynomial time. For completely solving problem instances that have industrial merit, computationally efficient solution techniques that combine the underlying concepts of branch-and-bound aided by filtered-beam search, and tabu search will be developed and tested. The lower-bounding mechanisms will be embedded in these techniques to not only seek solutions with guaranteed quality, but also use them advantageously to terminate the search to enhance computational efficiency. For the total completion time minimization problem with no carry-over setups, an approach based on an equivalent formulation of the asymmetric generalized traveling salesman problem will be investigated. Finally, the solution techniques developed will be tested with data obtained from industrial collaborators to validate their computational efficiency and ability to obtain solutions with guaranteed quality.

The successful completion of this project will provide both electronics and hardware manufacturing companies with methodological frameworks for rapidly generating schedules with guaranteed quantifiable performance. The insightful research findings so obtained will also enhance the existing graduate courses in scheduling at Oregon State University and University of Texas at Dallas.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Design, Manufacturing & Industrial Innovation
Oregon State University

0094011

Title: **CAREER: Integration of Product and Process Design for Short Fiber Reinforced Polymer Composites**

Start Date: 05/01/2001

End Date: 05/31/2006

Total Activity Funding: $375K

Abstract: This Faculty Early Career Development (CAREER) project plans to put design optimization and product and process simulation into the core of polymer composites processing research. The focus on the integration of the fundamentals of materials processing and design via a new, comprehensive framework is promising for both manufacturing education and product realization in polymer composites processing. Today's successful engineering organizations continue to make progress towards incorporating manufacturing demands during a product's design. It is unfortunate, however, that at a time when computer simulation has revolutionized the way new products emerge, designers continue to employ ad-hoc methods to ensure that a product accommodates its manufacturing process and vice versa.

This research seeks a new approach that places product specifications and materials processing requirements on a common basis where product and process simulation and multidisciplinary design optimization methods are central. The focus is on short fiber reinforced thermoplastic products manufactured by the injection molding process where a product's structural performance is defined by it's fiber orientation, that is itself determined during production. Optimal designs will be computed based on mold filling simulation, fiber orientation prediction, and structural evaluation. Large-scale industrial products common to automotive design are to be considered. Additionally, this research recognizes the increased design emphasis in today's undergraduate engineering curriculum and will, therefore, study decision making through the merging of multidisciplinary design into the educational pedagogy. Educational activities include undergraduate and graduate instruction on multidisciplinary design, integration of computational design into student competitions, and an effort to make K-12 teachers more familiar with modern design methodologies.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Design, Manufacturing & Industrial Innovation
Colorado School of Mines

0115133

Title: **Integrated Material-Shape Modeling Using Approximate Distance Fields**

Start Date: 09/01/2001

End Date: 08/31/2004

Total Activity Funding: $270K

Abstract: The research objective of this project is to develop sound theoretical foundations, design computer representations and algorithms, and to implement an experimental system for integrated material-shape modeling of components with continuously varying heterogeneous and anisotropic materials. The key technical challenge is to create physically meaningful models and computationally effective representations of the material density functions defined over the boundary and the interior of the solid, given their description and/or variation on the known portions of the solid model. The proposed approach is

based on the method for transfinite interpolation that parameterizes the interior of any solid in terms of the approximate distance fields to the specified material features. A comprehensive approach to the problem of material modeling will explore three distinct, but related, topic areas: (1) representational issues, (2) algorithms and systems, and (3) applications in design and manufacturing of parts with heterogeneous material properties. The results of the research will be tested in a prototype system based on a commercial solid modeler.

Successful completion of the project should lead to substantial progress in enabling and integrating modeling, design, and manufacturing of heterogeneous and anisotropic parts. Such components are becoming increasingly important due to emerging techniques in design of functionally graded materials and solid free-form fabrication techniques (such as layered manufacturing) that allow local material composition control. The anticipated advantages of the new technology include exactness of representation, independence from interior discretizations, complete automation, guaranteed analytical properties, and compatibility with existing standards for geometric modeling and data exchange.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Design, Manufacturing & Industrial Innovation
University of Wisconsin Madison

0122227

Title: **Scalable Enterprise Systems Phase II: Discrete Event System Specification (DEVS) as a Formal Modeling and Simulation Framework for Scaleable Enterprise Design**

Start Date: 09/01/2001

End Date: 09/30/2003

Total Activity Funding: $350K

Abstract: This Scalable Enterprise Systems Phase II project will develop the Discrete Event System Specification (DEVS) Formal Framework for Scalable Enterprise Design and extend earlier-developed DEVS-based modeling and simulation environments to support several real world test cases. As the Internet expands toward 1 billion nodes forming a highly interconnected and computationally powerful medium, and companies increase specialization and horizontal layered organization, new complexity and dynamics are emerging. Scalability, the ability to avoid performance degradation and system breakdown as the scale of activity greatly increases, is one of the urgent global problems that needs to be addressed. This research will seek to enhance scalability at three inter-related levels of abstraction: the Enterprise Architecture level, the Information Technology Infrastructure level, and the Modeling and Simulation level. Earlier research developed a theoretical foundation for architecting a major responsibility of enterprise systems -- to ensure that the right information about the enterprise is available to decision makers at the right time. Having extended the DEVS formalism to express time-critical behaviors in enterprise data management, the researcher proposes to implement the extended DEVS functionality by suitably extending the distributed real-time execution environment previously developed in NSF-sponsored research. This environment will be tested by two diverse applications: a small scale but complete and real factory automation test bed and a large-scale web-hosting service for e-business.

The Integrated Manufacturing Technology Initiative (IMTI) sponsored by the primary governmental funding agencies (NIST, DOE, NSF, and DARPA) states that modeling and simulation are emerging as key technologies to support manufacturing in the 21st century. This research will attempt to fill in some of the gap between the current state of the art and the IMTI vision of the future. In this vision enterprise

processes, equipment and systems are linked via a robust communications infrastructure that delivers the right information at the right time; and integrated enterprise management systems that ensure that decisions to be made in real-time and on the basis of enterprise-wide impact. Achieving scalability in M&S and IT infrastructure will enable a wide array of M&S studies and implementations, as well as supporting the scalability of the future M&S-based networked, extended and distributed enterprise systems envisioned by IMTI.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Design, Manufacturing & Industrial Innovation
University of Arizona

0099804

Title: **Collaborative Research: GOALI: Integrated and Computerized Setup Planning and Fixture Design**

Start Date: 06/01/2001

End Date: 04/30/2004

Total Activity Funding: $199K

Abstract: The objective of this project is to research and develop an integrated framework for automatic generation of setup plans and fixture designs, applied to a wide range of components (prismatic, rotational, as well as irregular) that require machining in lathes, 3-axis machines, and 5-axis machining centers using modular, standard, or dedicated fixtures. Setup planning and fixture design are two closely related tasks. While setup planning is constrained by fixtures to be applied, it also provides guidelines for fixture design. The cyclic interaction creates the 'chicken or egg' dilemma, which is the main research barrier. This problem will be solved as follows. First, a graph representation is developed to capture the feature/tolerance relationship of a product model. Through the recognition of design datum frames, the graph is transformed to a datum-machining surface relationship graph (DMG). With considerations of production scheme (integrated, distributed, or combined operations), fixturing constraints, machine tool capability, and tolerance decomposition, DMG will be converted into a setup graph. Tolerance stack-up analysis and setup plan verification is then followed to provide information for fixture design.

If successful, this research will yield both basic and applied advances. As basic research, it will provide a generalized methodology to unify current research results in setup planning and fixture design to achieve smooth integration of computer-aided design (CAD) and computer-aided manufacturing (CAM). It will also shed light on mathematics-based tolerance analysis. For practicing engineers, it will allow them to incorporate setup generation and fixture design capability into existing CAD/CAM software tools; thus, dramatically improve user productivity. The incorporation of the research results into course curriculum will broaden mechanical, industrial, and manufacturing engineering students' knowledge spectrum; thus, better preparing them for the knowledge intensive and multi-disciplinary working environment in the 21st century.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Design, Manufacturing & Industrial Innovation
Worcester Polytechnic Institute

0114903

Title: **Modeling Accelerated Degradation Data for Product Reliability Improvement and Warranty Analysis**

Start Date: 09/01/2001

End Date: 08/31/2004

Total Activity Funding: $275K

Abstract: This grant supports research for deriving new methods for accelerated degradation testing, or ADT, which involves analyzing product or system degradation in various high stress environments in order to predict product lifetime or system performance. The research concentrates on existing gaps in current test methods used in industry, and works to extend these current methods to a larger domain of problems, including non standard degradation models that describe more realistic product degradation scenarios in manufacturing. Initial work is based on applied problems with vacuum fluorescent displays (VFDs), light-emitting diodes, and fiber optics manufacturing. VFD performance helps to motivate such models. Emitted electrons from its cathode serve to eliminate impurities in the vacuum, and VFD light intensity actually increases up to a certain point of time before it decreases due to age-induced degradation. Standard ADT models cannot characterize this phenomenon. Specific developments of this research include: (1) A general framework for stress dependent degradation models based on physically motivated degradation paths; (2) Building formulas for failure times of various complex (non-linear) ADT models, along with uncertainty estimates based on statistical resampling methods; (3) Combining failure time data with separate sets of degradation data to improve product lifetime estimates; and (4) Finding optimal test procedures (in terms of information gained) based on time and cost constraints associated with product development. The ADT models include (nonlinear) random coefficients to reflect variability between test units. Bootstrap resampling procedures are derived to ascertain uncertainty because simpler variance approximations are not generally available with such random coefficient degradation models.

With degradation data, the proposed estimates of the product failure time distribution serves as a key quality measure for evaluating a company's process improvement in highly reliable products, and can help company managers decide their product warranty policy. If successful, the results of this research can strongly affect process condition changes, material selections, equipment innovations, maintenance schedule revisions and other production operation changes. Thus, the research provides valuable information for companies to improve their operation efficiency and profitability.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Design, Manufacturing & Industrial Innovation
Georgia Tech Research Corporation, Office of Sponsored Programs

0113745

Title: **ITR/AP: Simulation of Machine-Medium Interaction in a Real-Time Virtual Environment**

Start Date: 08/15/2001

End Date: 07/31/2004

Total Activity Funding: $400K

Abstract: This project is a joint multidisciplinary industry-academia research effort to develop an advanced virtual reality (VR) environment for modeling earthmoving equipment interaction with the surrounding medium such as soil. The project will take advantage of rapid developments in hardware, software and information technology to develop a real-time virtual environment for machine-medium interaction that includes realistic force-feed back. The proposed development will enhance the design of the earthmoving equipment and improve the design cycle. It will also open up new venues for application of VR for machine medium interaction. This project will greatly benefit from leveraged resources provided by Caterpillar, Inc. The research team will develop an original neural network (NN) based real-time soil medium model that can be used to simulate soil response due to manipulation by earthmoving equipment. The proposed model will be mechanistically accurate and run in real-time. It will simulate the soil resistance and the interactive forces between the medium and the earthmoving equipment. The NN model will be trained using data sets developed from non-real time simulations using the discrete element method. Data sets of soil and earthmoving equipment response will also be developed from full-scale field tests at Caterpillar, Inc. proving ground in Peoria, Illinois. The research team, in cooperation with the National Center for Supercomputing Applications (NCSA), will implement the new NN soil model in Cave Automated Virtual Environment (CAVE). A new object-oriented vehicle prototyping system (VPS) will be developed in this virtual environment. A force feedback link will be developed representing the medium resistance provided by the NN soil model to the vehicle dynamics model. The real-time virtual environment will enhance the design verification tools available to the earthmoving equipment manufacturing industry and reduce the number of costly field trials for new equipment designs. The ideas and methodology that will be developed for the real-time VR environment have a wide range of applications such as simulation of slope failures and avalanches as well as bulk and powder material handling in agricultural, mining and manufacturing applications. The proposed VR environment can potentially be used in space exploration of other planets where it is necessary to troubleshoot a remote controlled vehicle interacting with the soil medium on the planetary surface in real-time. This project brings together specialists in 1) computational intelligence and soil medium modeling from the Department of Civil and Environmental Engineering at UIUC, 2) virtual reality and computer science from NCSA at UIUC, and 3) earthmoving equipment design and control at Caterpillar, Inc. Close coordination among the team members will ensure a strong exchange of ideas between academia and industry.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Civil and Mechanical Systems
University of Illinois, Urbana-Champaign

0010032

Title: **GOALI/Collaborative Research: Capacity and Flexibility Investment Decisions in a Make-to-Order Environment**

Start Date: 06/01/2001

End Date: 05/31/2004

Total Activity Funding: $150K

Abstract: This Collaborative Grant Opportunity for Academic Liaison with Industry (GOALI) project will study strategic capacity planning decisions and their impact on the supply chain in a make-to-order environment. The project will construct analytical models and develop analytical, numerical, and simulation methods that will be tested in General Motors' environment to guide the research direction and ensure their practicality and ease of implementation. To provide their customers with customized products within reasonable lead-times at competitive prices, firms need to shift to make-to-order production where adequate capacity decisions are even more important than in the past. For a make-to-order strategy to be successful, supply and demand need to be reasonably balanced. This can be achieved through: (1) manufacturing flexibility, so that capacity can be shared among different products, (2) price flexibility, so that demand can be managed, and (3) delivery-time flexibility, so that demand coming from time-sensitive customers can be shifted in exchange for a price break. The project will study the effect of each of these levers on supply chain performance and on capacity requirements to offer guidance to companies on the design and management of their make-to-order production systems. In addition, the plan is to integrate the capacity investment decisions for products and additional features or options (e.g., vehicles and leather seats). Several issues need to be considered in the capacity analysis for these options: (1) The option and vehicle model capacity decisions are interdependent. (2) Demand for the various options might be correlated. (3) Customers have a different attitude towards different options. For example, they might not buy a car without an automatic transmission, but may accept other missing options, such as a vanity mirror. This leads to very different risks of over- and under-capacitizing for each particular option. Thus, the project will develop models that address capacity-pricing decisions considering customers' preferences.

The research will provide: (1) Analytical results and insights for better capacity planning in a make-to-order environment, and (2) Tools for vehicle and option capacity planning that consider uncertainty, demand management techniques, and the impact on operational supply chain costs. Also, the projected outcome is to develop general models that can be used in a wide range of industries and demonstrate their practical impact by implementing/testing them at General Motors.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Design, Manufacturing & Industrial Innovation
Virginia Polytechnic Institute and State University

0200346

Title: **Simulations and Novel Methods for Microwave Processing of Polymers and Composite Materials**

Start Date: 05/01/2002

End Date: 04/30/2005

Total Activity Funding: $360K

Abstract: Microwave processing of polymer composite materials is an increasingly important technology for the polymer industry and its customers. Polymer composites combine the best properties of its constituent parts, namely a polymer matrix along with a suitable filler such as glass, to achieve a new material that has superior properties to the original materials, including low cost. Desirable and achieved properties of polymer composite materials include improved strength and temperature tolerance among others. Microwave processing, as compared to convection processing, has been shown to yield superior mechanical properties as well as be more efficient in terms of energy requirements and time-to-manufacture. Microwave processing of polymer composites is similar to microwave heating of food in the ubiquitous microwave ovens. The electromagnetic energy within the microwave oven interacts with the material being processed and heats it throughout the volume rather than via surface heating. The temperature change causes a change in polymer composition (hence the curing process). This coupling between electromagnetic energy, temperature rise, and composition changes is not well understood resulting in unexplained over- and under-cured regions in the composite.

The Departments of Chemical Engineering and Materials Science, Electrical and Computer Engineering, and Mechanical Engineering are combining expertise in polymer processing, microwave energy, and thermal propagation to investigate the fundamental interaction between electromagnetic energy absorption, temperature change, and composition change. In addition, development of a multi-port microwave applicator is planned that will significantly reduce the cost of applicator construction due to the use of lower power microwave sources than is used in practice today. Both theoretical modeling of these coupled phenomena as well as experimental verification of results will be pursued. It is anticipated that the results of this project will be an improved microwave applicator and processing protocol that will significantly improve industrial polymer composite processing methods. The principal investigators are actively participating in a program at MSU to provide education and mentoring to underrepresented minority and women engineering students at both the undergraduate and graduate levels.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Design, Manufacturing & Industrial Innovation
Michigan State University

0091359

Title: SBIR Phase II: An Intelligent Three-Dimensional (3D) Mosaic Tool for Multiple 3D Images Integration

Start Date: 04/01/2001

End Date: 01/31/2003

Total Activity Funding: $500K

Abstract: This Small Business Innovative Research (SBIR) program investigates a novel software tool for integrating multiple 3D images. Three-dimensional (3D) modeling of physical objects and environment is an essential part of the challenges for many multimedia tasks. However, most physical objects self occlude, and no single view 3D image suffices to describe the entire surface of a 3D object. Multiple 3D images of the same object or scene from various viewpoints have to be taken and integrated in order to obtain a complete 3D model of the 3D object or scene. This process is called the "3D mosaic". The primary objective of this SBIR effort is to develop a fully automatic and intelligent software tool that is able to mosaic (i.e., align and merge) multiple 3D images of the same object taken from different viewpoints, without a priori knowledge of camera positions. The main innovations of this proposed effort are threefold: (1) an intelligent alignment method that is able to register multiple un-calibrated 3D images without needing any priori knowledge of camera location and orientation; (2) a seamless merge method to "stitch" together the aligned 3D images using the fuzzy logic principle; and (3) an intelligent 3D image compression algorithm that preserves 3D image geometric features while achieving high compression ratio.

The 3D Mosaic technique to be developed under this SBIR program has enormous commercial applications, including industrial design and prototyping, reverse engineering, manufacturing part inspection, part replacement and repair, animation, entertainment, 3D modeling for WWW documents, archiving, virtual reality environment, education, virtual museum, commercial on-line catalogues, etc. It will become an important part of future 3D TV technology.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Design, Manufacturing & Industrial Innovation
Genex Technologies, Incorporated

131809

Title: CAREER: Robust Digital Model-Based Fault Detection and Isolation for Nonlinear Processes

Start Date: 04/01/2002

End Date: 02/2/2006

Total Activity Funding: $375K

Abstract: The main area of the planned research project is the development of a systematic, comprehensive and practical framework for digital monitoring, and fault detection and isolation (FDI), of chemical, biochemical, microelectronics, etc. manufacturing facilities. In particular, the primary objectives include: (i) The study of the fundamental problem of the design of reliable robust digital model-based monitoring and FDI systems for nonlinear processes in the presence of model uncertainty and unknown disturbances. (ii) The development of the appropriate software tools for the effective digital implementation of the planned process monitoring and FDI scheme. (iii) The real-time experimental implementation of the re-

sults of the aforementioned theoretical and computational studies on a pilot-scale polymerization reactor, as well as a bioreactor.

An integral part of this project is the realization of educational goals that could complement and enrich these research activities. Aligned with the principles and vision of an innovative educational framework being developed at the Worcester Polytechnic Institute (WPI), the primary educational objectives are: (i) The formulation of open-ended projects with a concrete flavor and orientation towards process dynamic modeling, monitoring and diagnostics, that will be jointly defined by professional practitioners in industry and the PI. These projects will be conducted on the industrial site, and occasionally, in an international setting. (ii) The utilization of recent advancements in computing and communications technology in order to provide a virtual learning environment that can (a) enhance the learning experience of current WPI students by elucidating key concepts in process modeling, dynamics, monitoring and diagnostics through animation and advanced graphics, and (b) be remotely accessed by educational institutions in socio-economically distressed zones in the state of Massachusetts with a large minority student population. The objective is to provide direct remote access to real, as well as a virtual process control, monitoring and diagnostics laboratory, in order to enhance scientific literacy and awareness, and to broaden current educational opportunities for those who need them most.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Chemical and Transport Systems
Worcester Polytechnic Institute

0122214

Title: **Scalable Enterprise Systems Phase II: Agent Based Scalable Enterprise System for Enterprise Co-design**

Start Date: 10/01/2001

End Date: 09/30/2004

Total Activity Funding: $498K

Abstract: The objective of this Scalable Enterprise Systems award is the creation of an agent-based framework for the simulation of product design, marketing and supply-chain as collaborative processes. This project will develop the enabling theories and technologies needed to support its realization. The framework will use computational agents modeling the human behavior, artificial agents modeling synthetic economies, and constructive agents to address strategic, tactical and operational decision-making problems in simulating product life cycle. These agents use both analytic models and adaptive algorithms such as generic algorithms, fuzzy logic, and neural networks. The agents will compete to provide solutions in these simulations using innovative market metaphors such as auctions and recommendation systems. The research tasks include requirements analysis, preliminary functional analysis, methodology development, initial prototyping, testing, and specifications for the framework.

If successful, this research will allow organizations to become aligned to and focused on to changing markets and changing customer values. The proposed collaborative design framework will test strategies necessary to ensure that the product delivery process, the product development process, and marketing initiatives are aligned to address the multiple dimensions of customer values simultaneously. The results will apply in the modeling of the supply chain for convergence technologies and the development of business models for electronic bandwidth exchange. The prototype will be used to support teaching in several courses in Economics and Management.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Design, Manufacturing & Industrial Innovation
Purdue University

0122207

Title: **Scalable Enterprise Systems Phase II: Supply Chain Optimization and Protocol Environment (SCOPE) - A Rapid Prototyping and Modeling Tool for Extended Enterprises**

Start Date: 09/01/2001

End Date: 08/31/2004

Total Activity Funding: $622K

Abstract: The objective of this Phase II Scalable Enterprise Systems project is to develop a Supply Chain Optimization and Protocol Environment that emulates the behavior of supply chains involving multiple, independent, goal-seeking entities over time. Entities will be represented by novel optimization models that capture the key decision variables and technological constraints, while retaining enough special structure to allow efficient solution. Interactions among entities will be described through protocols that specify what goods, money, and information pass among entities, in what order entities make decisions, how information is processed by each entity to make its decisions, and how entities respond to unforeseen events that do not match their plans. The approach will allow users to represent a range of different modes of interaction among entities in the supply chain, which, although simplified relative to industrial practice, should provide insights into many cases of practical interest. By focusing on the policy level of analysis, it provides sufficient granularity for evaluating high-value supply chain opportunities, and assessing the associated risks, unencumbered by the transactional detail of existing modeling systems.

If successful, this project would provide managers with a tool for rapid prototyping of supply chain proposals that would permit them to evaluate possibilities without either implementing an untested idea or waiting for competitors to do it and risking loss of market share. Researchers would be provided a test bed for assessing how well theoretically derived results generalize to different modes of operation that strain some of the original assumptions, and for experimenting with forms of supply chain collaboration too complex for treatment analytically. Educators will be able to explore realistic cases with students by varying model parameters and displaying the results in near real time.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Design, Manufacturing & Industrial Innovation
Purdue University

0121902

Title: **Scalable Enterprise Systems Phase II: Network-Based Distributed Relational Decisions Framework**

Start Date: 09/01/2001

End Date: 08/31/2004

Total Activity Funding: $528K

Abstract: This Scalable Enterprise Systems Phase II project effort will build upon the work in Phase I by: (1) extending the relational decision framework to support efficient integration of distributed heterogeneous databases into a global decision framework; (2) building on the theory of co-evolutionary search algorithms using intelligent agents to address issues in multi-criteria decision-making; and (3) developing a comprehensive model of dynamic decision networks, integrating characteristics of software algorithms and network hardware and software for communications in order to evaluate performance and guide system design. Advances in information technologies are driving fundamental changes in the processes and organizations of global enterprises. Innovations in software, networks, and database systems enable widely distributed organizations to integrate activities, share information, collaborate on decisions, and execute transactions. While many existing tools and techniques of information infrastructure may be adopted and implemented to support these enterprise applications, there has been little focused research to provide a scientific basis to support these developments.

A major outcome of this research will be an integrated demonstration of network-based distributed decision methods applied to real industrial problems and evaluated through sophisticate evaluation and simulation methods. The outcomes of this work offer advantages of local autonomy, reliability, improved performance, scalability, shareability, data confidentiality, and efficient software support for a new class of enterprise-level software systems. This research project includes efforts to incorporate these ideas into existing and new educational programs and courses with special attention to the recruiting and retention of underrepresented groups.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Design, Manufacturing & Industrial Innovation
Rensselaer Polytechnic Institute

0121667 and 0121360

Title: **ITR/AP COLLABORATIVE RESEARCH: Real Time Optimization for Data Assimilation and Control of Large Scale Dynamic Simulations**

Start Date: 10/01/2001

End Date: 08/31/2006

Total Activity Funding: $1,145K – Carnegie Mellon University

Total Activity Funding: $550K – William Marsh Rice University

Abstract: This project will create and apply algorithms and software tools for on-line simulations that continuously (1) assimilate sensor data from dynamic physical processes, and (2) generate optimal strategies for their control. A number of critical industrial, scientific, and societal problems stand to benefit from this research such as aerodynamics, energy, geophysics, infrastructure, manufacturing, medicine,

chemical process and environmental applications; two of these will be the focus of the current research. In these and many other cases, the underlying models have become capable of sufficient fidelity to yield meaningful predictions, provided unknown parameters (typically initial/boundary conditions, material coefficients, sources, or geometry) can be estimated appropriately using observational data.

The critical step is the solution of a large-scale nonlinear optimization problem that is constrained by the simulation equations, typically PDEs or their reduced order models. A data assimilation phase will seek to minimize the mismatch between sensor data and model-based predictions by adjusting unknown parameters of the PDE simulation, and the optimal control phase will find an optimal control strategy based on the updated model.

Despite advances in hardware, networks, parallel PDE solvers, large-scale optimization algorithms, and real-time ODE optimization, significant algorithmic and software challenges must be overcome before the ultimate goal of real-time PDE data assimilation and optimal control can be realized. Needed are fundamentally new PDE optimization algorithms that must: (1) run sufficiently quickly to permit decision-making at time scales of interest; (2) scale to the large numbers of variables and constraints that characterize PDE optimization and processors that characterize high-end systems; (3) adjust to different solution accuracy requirements; (4) target time-dependent objectives and constraints; (5) tolerate incomplete, uncertain, or errant data; (6) be capable of bootstrapping current solutions; (7) yield meaningful results when terminated prematurely; and (8) be robust in the face of ill-posedness.

To create, apply, and disseminate the enabling technologies for real-time PDE data assimilation and optimal control, the project will: (1) Develop algorithms and tools for real-time data assimilation and optimal control that meet the above specifications for a class of important applications. (2) Implement and publicly distribute these algorithms within an object-oriented framework that incorporates problem structure, interfaces easily with high performance PDE solver libraries fosters applicability of our tools to a broad range of real-time data assimilation and optimal control problems, and enables extension of the algorithms without interfering with applications. (3) Apply these algorithms and tools to two critical environmental and industrial problems: modeling and control of chemical vapor deposition (CVD) reactors and of wildland firespread. (4) Interact and work with other user communities to ensure that the algorithms and software we produce are useful across a broad range of applications.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Advanced Computer Infrastructure and Research
Carnegie Mellon University
William Marsh Rice University

0115434

Title: **Collaborative Research: Designing Responsive Product and Service Fulfillment Networks Using Dynamic Adaptive Modeling**

Start Date: 09/01/2001

End Date: 08/31/2004

Total Activity Funding: $172K

Abstract: This collaborative research project addresses a new large-scale optimization model, called Network Design with Service Guarantees (NDSG), that simultaneously incorporates revenue, cost, and serv-

ice (end-to-end delay) considerations. Though of immense practical significance, the NDSG model is very difficult to solve both from theoretical and computational perspectives. The goal is to develop and test effective solution procedures using state-of-the-art optimization techniques that can exploit the NDSG problem's special mathematical structure. Accordingly, the project entails both theoretical and empirical investigations, including developing and characterizing alternative problem formulations, analyzing their structural properties, designing specialized solution algorithms, and testing these methods using realistic data. To solve the problem, a new family of optimization algorithms that dynamically reformulates the problem, and correspondingly adapts the solution approach by combining decomposition and model strengthening techniques will be investigated. It is expected that the core research contributions-a new modeling paradigm, a novel solution approach, and algorithmic implementation-will also extend to other large-scale optimization models. Communication and physical distribution capabilities have become critical in the new networked economy. Organizations have come to rely on these capabilities to establish tightly integrated partnerships that can effectively serve diverse market needs for products and services. Delays or failures in the movement of information or goods can have debilitating consequences not only for supply chains but also for services such as emergency operations, air traffic control, and financial systems. Decisions regarding the configuration of communication and distribution networks needed to support coordination and collaboration have strategic importance both because they entail massive investments of billions of dollars and because a network's topological design largely determines the level of service it can provide. Consequently, optimization tools are widely used in practice to design product and service fulfillment networks, and network design continues to be a very active research area.

Designing optimal network configurations entails complex tradeoffs between conflicting objectives such as maximizing profitability, ensuring adequate resource utilization, improving service levels, and so on. Classical optimization models, which focus primarily on cost minimization, tend to design sparse networks that exploit economies of scale but are not robust in terms of service and reliability. The project will provide opportunities for graduate students to conduct thesis research, and enrich graduate courses in optimization and operations modeling.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Design, Manufacturing & Industrial Innovation
University of Pittsburgh

9527190

Title: **HPCC: A Distributed Architecture for Rapidly Reconfigurable Assembly Systems**

Start Date: 11/01/1995

End Date: 10/01/1999

Total Activity Funding: $2,240K

Abstract: This research aims to improve assembly in product manufacturing. Assembly is a difficult and time-consuming process to automate, especially when small tolerances are necessary. This architecture for agile assembly is a strategic framework using agent-based robotic elements that are precise, modular, and extensible. These elements form sets of leased self-contained software/hardware modules that can be programmed and operated over the Internet, and can be brought together to form miniature agile factories for assembly. Such a scheme requires a combination of intelligent networked communication, distributed computing resources using high-performance processors, and distributed sensor/actuator subsystems of novel design. Design and construction of a prototype miniature factory according to the principles of agile

assembly architecture will be carried out to validate the research and provide a unique and powerful re-configurable platform for assembly research and evaluation by industry. Partial assembly of magnetic storage disk drives will serve as a testbed. This work aims to advance knowledge in three main areas: (1) seamless wide area and local area networking of distributed agents emphasizing high quality of service; (2) modular precision robotic assembly elements containing high-performance embedded processors; and (3) a comprehensive software environment for modeling, simulation, and programming of the miniature factories. The results of the research could allow manufacturers to develop a capability for geographically distributed design and deployment of assembly systems while providing drastically reduced changeover times, and higher quality.

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PARTICIPATING ORGANIZATIONS:

Carnegie Mellon University
NSF Division of Design, Manufacturing and Industrial Innovation

9623614

Title: **Modeling Complex Physical and Computational Environments (CISE Research Infrastructure)**

Start Date: 09/01/1996

End Date: 08/01/2001

Total Activity Funding: $1,997K

Abstract: This award is for the creation of a Modeling and Simulation Support Facility, constituting vital infrastructure for work on end user applications in novel computer architectures, manufacturing and design, process control, teleoperations, and medicine; while also serving as a testbed for innovations in machine architecture, hardware, and software systems. The Modeling Facility will use state-of-the-art technology to achieve high-bandwidth, low-latency machine-to-machine communications, resulting in significant computational leverage. The use of multiple heterogeneous and potentially specialized computers in a tightly coupled communication environment permits model builders to explore novel parallel simulation methods that can greatly reduce simulation run times. This increase in capability permits entirely new classes of critical problems to be solved. Modern simulations produce large quantities of data, the interpretation of which may not be immediately apparent. Thus, the second central component of the Modeling Facility is a large capacity storage management system. Finally, the Modeling Facility will be equipped with several special purpose devices that can exploit the communications and data management facilities to tackle large-scale problems that are currently infeasible in a traditional academic computing environment.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Experimental and Integration Activities
University of Utah

9615858

Title: **Mathematical Sciences: VIP/ Virtual Integrated Processing of YBCO Thin Films**

Start Date: 07/01/1997

End Date: 06/01/1999

Total Activity Funding: $1,864K

Abstract: This is a multidisciplinary project focused on modeling, simulation, and control of metalorganic chemical vapor deposition (MOCVD) of YBa2Cu3O7-x (YBCO) thin films. The project team is composed of senior investigators from four universities (California Institute of Technology, New York University's Courant Institute, the University of Minnesota, and the Colorado School of Mines), working together with an industrial partner, Superconductor Technologies, Inc. (STI). Superconducting thin film devices have enormous economic potential in several applications, for example as compact, high-performance microwave filters. However, to make this technology economically viable, a high-throughput, low-unit-cost superconducting thin film deposition process must be developed. One promising technique is metalorganic CVD. The goal is to use mathematical tools and methods to enable virtual prototyping and control of a robust, high-throughput MOCVD process for manufacturing YBCO thin films suitable for microwave filter devices. The work will span several fields, and will include * fundamental investigations of epitaxial YBCO film growth * development of predictive models for MOCVD of YBCO based on fundamental principles, * simulation-driven design and construction of an advanced, prototype MOCVD reactor with integrated sensing and control * and development and experimental validation of model-based process control strategies. Funding for this activity will be provided by the Division of Mathematical Sciences, the MPS Office of Multidisciplinary Activities, the NSF Engineering Directorate, and by DARPA.

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PARTICIPATING ORGANIZATIONS:

California Institute of Technology
Colorado School of Mines
DARPA - Defense Advanced Research Projects Agency
New York University - Courant Institute
NSF Division of Mathematical Sciences - DMS
STI
University of Minnesota

85569

Title: **Computational Nano-Engineering for Patterned Magnetic Nanostructures**

Start Date: 09/01/2000

End Date: 08/01/2003

Total Activity Funding: $1,680K

Abstract: Computational nano-engineering is an emerging field of research aimed at developing nanoscale modeling and simulation methods to enable and accelerate the design and development of functional nanometer-scale devices and systems. Just as microfabrication has led to microelectronics revolution in the 20th century, nano-precision engineering will be a key to the nanotechnology revolution in the 21st century. A major challenge in this technology is to fabricate patterned nanostructures. The objective of the proposed research is to develop multiscale modeling and simulation methods for nanopatterning. As a prototype example with comprehensive industrial impact, we will focus our efforts on nanopatterning of magnetic nanostructures for high-density information storage device applications where the control of grain size distribution is becoming increasingly important, and the drive for decreased media noise and increased storage density is pushing the grain size below the 10 nm regime. We propose a systematic study of the mechanisms that control the grain size and grain size distribution in magnetic thin films. We will use continuum theories to model the length scales determined by competing mechanisms of epitaxy, surface stress, surface energy, strain energy, compositional free energy and quantum energy. We will develop kinetic Monte Carlo and quantum simulations to simulate nanoscale self-organization for creating magnetic thin film media with ultra-fine grain sizes and ultra-narrow grain size distributions. The simulation tools will allow us to quantitatively investigate nanofabrication processes, and in particular, to predict the grain size and grain size distribution in magnetic nanostructures. The proposed project will have immediate impact on the magnetic information storage nanotechnology by providing industry with the first theoretical tool to analyze nanofabrication processes based on the state-of-the-art knowledge of nanoscale modeling and simulation. This project will allow engineers to reduce or eliminate costly and slow processes of developing new nanostructured materials. Through the proposed research, we will develop the framework of computational nanopatterning technology which will benefit the whole spectrum of current nanotechnology challenges. This project will lead to better understanding of the basic mechanisms that control the structuring of materials at the nanometer scale. The Kinetic Monte-Carlo simulation and quantum simulation methods developed under this project will have far-reaching significance for the design and manufacturing of nanodevices.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Engineering Education Centers
Stanford University

9615877

Title: **Mathematical Sciences: VIP/Thin Film Deposition: Atomic Level Simulations, Verification, and Implementation**

Start Date: 07/01/1997

End Date: 06/01/1999

Total Activity Funding: $1,393K

Abstract: This award will support a multi-disciplinary collaboration on the development of mathematical and computer simulation techniques which are sufficiently sophisticated, flexible and robust to meaningfully predict a complex manufacturing process. Success in this program will represent a significant step forward in the complexity of real manufacturing issues which can be effectively addressed by simulation. The specific process which will be addressed in this program is the growth of multilayer metal and dielectric films, which need to be patterned with precision of a fraction of a micron for contacting the tens of millions of individual device elements within modern microelectronic circuits. The program will combine mathematical models with atomic-level computer simulations to predictively model the film growth over length scales ranging from the atomic to the microstructural. These predictions will then be compared with atomic-scale characterization (using state-of the-art electron and ion microscopy techniques) of experimental depositions, to refine our understanding of the exact physical processes describing film growth, and to verify and refine the predictive models. The experimental depositions will be performed both with state-of-the-art research systems which provide atomic-scale control of film growth, and with real microelectronics processing facilities at Lucent Technologies. This program will assemble a team of internationally recognized mathematicians, physicists and materials scientists. The program goals are to improve substantially the deposition of microelectronic contact layers, a central challenge to the two hundred billion dollar microelectronics industry, and to expand current acceptance of what is technically "possible" in terms of predictive modeling of complex manufacturing processes. Funding for this activity will be provided by the Division of Mathematical Sciences, the MPS Office of Multidisciplinary Activities, the NSF Engineering Directorate, and by DARPA.

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PARTICIPATING ORGANIZATIONS:

DARPA - Defense Advanced Research Projects Agency
NSF Division of Mathematical Sciences - DMS
University of Illinois

9617750

Title: **Distributed Design and Fabrication of Metal Parts and Tooling by 3D Printing**

Start Date: 05/01/1997

End Date: 04/01/2000

Total Activity Funding: $1,350K

Abstract: The goal of this research is to provide a "clean interface" between design and fabrication for mechanical parts to be made by Solid Freeform Fabrication using Three Dimensional Printing as a prototypical process. The "clean interface" will be modeled after the practice in the design of integrated circuits. It is predicated upon the availability to the designer of representations capable of expressing a wide range of fabrication capability of Three Dimensional Printing, coupled with the ability to ensure that designs created with this representation are manufacturable. This program will investigate: (1) representations for parts with local composition control, a capability not now addressed by existing representations; (2) design rules which capture in simple terms the limitations of the fabrication technology, such as limitations on variation of local composition; (3) simulations for aspects of process technology which cannot be captured as simple design rules, for example for the surface texture resulting from layering; and (4) the derivation of instructions for a Three Dimensional Printing machine from comprehensive part representations, which include local variation in composition. This program will also operate an interactive communication link to designers in order to test hypotheses about how designers use the tools provided to them. Parts will be fabricated based on remote input from designers at sites in industry, academic research programs, and in an undergraduate course in manufacturing. A successful "clean interface" between design and fabrication will allow the designer of parts to be made by Solid Freeform Fabrication to send information to the fabricator and to get back a good part without any discussion with the fabricator. This clean separation between design and fabrication for mechanical parts will: (1) facilitate distributed design and fabrication; (2) lower the barriers to entry for users of Solid Freeform Fabrication; and (3) empower designers to make more complete use of the flexibility of Solid Freeform Fabrication processes, while guaranteeing manufacturable designs.

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PARTICIPATING ORGANIZATIONS:

Defense Advanced Research Projects Agency
Massachusetts Institute of Technology
NSF Division of Design, Manufacturing and Industrial Innovation

9713549

Title: **Operational Methods in Semiconductor Manufacturing: Methods for Modeling Stochastic Processes in Semiconductor Manufacturing**

Start Date: 09/01/1997

End Date: 08/01/2000

Total Activity Funding: $800K

Abstract: This award provides funding to investigate how the random elements of semiconductor manufacturing impact overall factory productivity. Algorithms will be created and tested for simulating dependent, transient random processes such as product demand, tool reliability, operator availability, and step yield. Statistical procedures will be developed for determining the types and amount of data that are needed to accurately represent these processes in factory queuing models and simulations. A central part of the research program will be designing efficient experimental procedures for optimizing the performance and validity of factory models. Experimental and analytical techniques for using these models to support the optimal timing of resource investments such as tool purchases and personnel cross-training will also be developed. If successful, this research will provide engineers in the semiconductor industry with fundamental knowledge necessary for the creation of valid models and efficient analytical tools useful in designing semiconductor fabrication facilities. A key to improving the cycle times and throughput of these multi-billion dollar factories is the identification and control of the random factors of production. Conventional semiconductor factory models assume that independent and identically distributed random input processes produce steady-state output processes with known performance objectives, economic parameters, and constraints. The realities of semiconductor fabrication are quite different. In the semiconductor industry, capacity requirements, product demands, and competitive cycle times are always changing, as are the very products, processes, and personnel skills involved. Currently, factory-level models are overly optimistic because they ignore many of the transient dependencies in the random phenomena found in real semiconductor manufacturing. This consistent optimism has had serious economic consequences. Valid factory models based on this research will be critical to the continued economic health of this vital industry. Furthermore, the costs of data collection are enormous. This research will provide guidelines for estimating how much data is necessary and how it should be used in engineering design. The modeling methodologies developed in this research will also help engineers to determine optimal settings of critical factory operating parameters that can make the difference between financial success and disaster.

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PARTICIPATING ORGANIZATIONS:

Cornell University

NSF Division of Design, Manufacturing and Industrial Innovation

9873196

Title: **Exploring the Black Box: Spatially Immersive Virtual Environments for Computational Engineering Research and Application**

Start Date: 08/01/1998

End Date: 07/01/1999

Total Activity Funding: $599K

Abstract: The procurement of a CAVE will allow the ERC 's computational infrastructure to advance the understanding of the output of the numerous simulations and data sets processed by the Center. It will allow the Center to better contribute to advancing the knowledge and technology base in virtual environments. The focus projects are drawn from application areas related to ongoing ERC research. The application areas are flow about manufactured objects (propulsors, propellers, and moving vehicles), i.e., CFD applications, meteorology and oceanography (METOC) visualization environments, and visualization of remotely sensed data. The research issues underlying these applications concentrate on distributed, multi-resolutional representations and visualization, compression, and human-computer interfaces (HCI) and human-factor issues. The first two areas of research will be addressed predominantly by the members of the Scientific Visualization Thrust of the ERC. The last research area will be addressed in collaboration with faculty from the Cognitive Engineering and Systems Laboratory (CESL) and the Institute for Signal and Information Processing (ISSP). The CAVE will also be used as an educational tool. The ERC will include its use in existing courses and will institute new course devoted to virtual environments.

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PARTICIPATING ORGANIZATIONS:

Mississippi State University
NSF Division of Engineering Education Centers

9908437

Title: **Design of Next Generation Factory Layouts**

Start Date: 09/01/1999

End Date: 08/01/2002

Total Activity Funding: $596K

Abstract: This grant provides funding for the development of design tools for layouts of factories that either operate in highly volatile environments or produce a large variety of products. For these factories, being able to quickly reconfigure resources to meet changing needs is critical. Therefore, a focus of this research is on identifying layout configurations that are highly flexible, modular and reconfigurable. Because the performance criteria of the flexible factory are different from those of the traditional factory (for example, scope is more important than scale, responsiveness is more important than cost, and reconfigurability is more important than efficiency), the existing performance metrics used to evaluate layouts reflect poorly these priorities. Consequently, this research will develop new evaluation criteria for layout design that explicitly account for flexibility and responsiveness. Since the operational performance of factories (for example, the ability to produce a large variety of products, manufacture products in small batches, offer customers short lead times, or introduce new products frequently) can be directly affected by layout, this research will also develop analytical models that allow better understanding of the relation-

ship between layout configuration and operational performance. If successful, this research will identify new layout configurations that are more suitable for the emerging needs of the agile factory. These layouts will be flexible, modular and more easily reconfigurable. Flexibility, modularity, and reconfigurability, will save factories the need to redesign their layouts each time their operating requirements change or new products are introduced. The new design tools will provide systematic and efficient methods for configuring and managing these new layouts. Being able to design layouts with the operational requirements of agility in mind (for example, higher variety, shorter time-to-market and shorter manufacturing lead times) will mean greater competitive advantage.

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9505674

Title: **3-D Model Building in Computer Vision: New Approaches and Applications**

Start Date: 09/01/1996

End Date: 08/01/1999

Total Activity Funding: $591K

Abstract: The project will develop new approaches for 3-D model building in computer vision. These models will based on stereo pairs and/or the 3-D surface data obtained by a laser scanner. For either of these modalities, the model building process consists of two mainly sequential steps. The first step provides a representation for 3-D objects; this step is called the Data Representation and Registration Phase (DRRP). The second step develops methods for 3-D model verification and is called the 3-D Model Verification Phase (MVP). Four research topics will be addressed while carrying out the proposed study: (i) design of a representational scheme in the form of a 3-D surface model describing various geometric and irregular objects, the input being stereo pairs and/or laser scanned data; (ii) development of methods for accurate fusion of data obtained from multi-views; (iii) development of methods for merging surface information in situations where both stereo imaging and laser scanners are available; and (iv) application of the methods used in (i)-(iii) in manufacturing and biomedical engineering.

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PARTICIPATING ORGANIZATIONS:

NSF Division of Electrical and Communication Systems
University of Louisville - Research Foundation

9800565

Title: **Process Optimization of Solid Freeform Fabrication Using Experimentation, Simulation, and Adaptive Statistical Models**

Start Date: 03/01/1998

End Date: 02/01/2001

Total Activity Funding: $569K

Abstract: The objective of this research is to create a methodology for optimizing manufacturing processes using statistical models. These models will be created from knowledge acquired from different sources, including heuristics, expert knowledge, physical experimentation, first principle relationships and large-scale computer simulations of physical models. Optimizing a manufacturing process requires an understanding of the influence and interactions of design and process variables on the final quality of the manufactured artifact - Variables are properties of the material (or combinations of materials) selected, of the physics of the process, of the geometry of the part, of the equipment settings, and of the manufacturing environmental conditions. The process modeling framework must be flexible and adaptable, so that models for subprocesses can be updated and adapted as processes evolve and new knowledge is acquired. This research focuses on a new class of manufacturing processes called Solid Freeform Fabrication (SFF) or layered manufacturing, which are changing traditional approaches to design and manufacture of mechanical parts. Better process models of SFF manufacturing processes will lead to faster development of rapid manufacturing processes and will accelerate their use and acceptance by industry. Good models will also allow better identification of design possibilities so that manufacturing considerations can be brought into the early phases of the design cycle. A methodology for creating and optimizing process models with differing levels of detail for different phases of the design cycle will remove impediments to the integration of design and manufacturing concerns. This work will also contribute to statistical model building by enabling users to incorporate the active and critical constraints on design variables, to handle high-dimensional and irregular parameter spaces efficiently, and to assess model reliability, predictive capability and parameter sensitivity.

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PARTICIPATING ORGANIZATIONS:

Carnegie Mellon University
NSF Division of Design, Manufacturing and Industrial Innovation

9520173

Title: **Numerical Classification of Microstructures**

Start Date: 05/01/1996

End Date: 04/01/1999

Total Activity Funding: $550K

Abstract: This research effort is directed towards improved capability for predicting the properties of manufactured items from the microstructure of the base material and the processing path that was used in production. To accomplish this it is necessary to describe the microstructure in quantitative terms; accordingly, image analysis systems and the interpretation of acquired microstructural information are examined to numerically describe microstructural assemblies. A majority of metal alloy microstructures,

such as those derived from solidification and casting, are not easily described in terms of Euclidean geometry. For these cases fractal analysis can be employed to make numerical statements about the microstructure, however chaotic it may be. The feasibility of this approach has been shown for distributions of graphite in graphitic cast irons and should apply to many other complex microstructures which presently defy quantitative numerical assessment. The research involves model alloy systems and actual industrial products, starting with cast irons and aluminum-based engine castings. Ford Motor Company and General Motors Corporation view this research as an important area of pre-competitive technology and are providing significant contributions to the program. While this program is academically stimulating, it has considerable industrial potential for predictive automation of manufacturing processes.

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PARTICIPATING ORGANIZATIONS:

Michigan Technological University
NSF Division of Materials Research

9978926

Title: **Aerosol Manufacture of Nanoparticles and Selected Applications**

Start Date: 09/01/1999

End Date: 08/01/2002

Total Activity Funding: $540K

Abstract: Fundamental understanding and modeling of the "laser ablation of microparticles" process and the extension of the process to the collection of unagglomerated nanoparticles on dry or wet surfaces is proposed. Nanoparticles of 5 to15 nm with narrow size distribution composed of various materials can be obtained with the suggested approach at large production rates. Modeling and experimental investigation will focus on nanoparticle nucleation and growth process, evaporation of materials by laser ablation, chemical changes in nanoparticles by varying the surrounding gas, and in situ particle size electrostatic selection. This is a multidisciplinary collaborative university-industry project (GOALI) between the University of Texas at Austin and DuPont Polymer and Electronic Materials Co. for the generation, characterization and use of nanoparticles with immediate application for thick film pastes. If successful, the research will advance understanding of ablation and nucleation processes, and will have application to generation of new materials and structures of importance in electronics, sensors and optical devices.

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PARTICIPATING ORGANIZATIONS:

DuPont Photopolymer & Electronic Materials
NSF Division of Chemical and Transport Systems
University of Texas - Austin

4.0 Overview of Other Recent Federally Funded R&D Projects Related to Modeling & Simulation for Manufacturing

70NANB6H2005

Title: **Solutions For MES-Adaptable Replicable Technology (SMART)**

Start Date: 05/01/1996

End Date: 09/01/2000

Total Activity Funding: $12,751K

Abstract: The time it takes to get a good idea into the marketplace often is what separates winners from losers. This argues for shorter design cycles and lower volume production of more customized product lines. Making this "agile manufacturing" work requires that organizations interconnect, software systems interoperate, and individuals interact -- information flowing freely and in usable forms among the people, equipment and computers of a manufacturing enterprise. The National Industrial Information Infrastructure Protocols (NIIIP) Consortium proposes to build upon its previous success in the design arena to develop an overarching system of algorithms, models, interfaces, decision tools and relevant practices under which a wide variety of automated manufacturing environments can work together. The proposed Solutions for MES-Adaptable Replicable Technology (SMART) will be an open, non-proprietary software framework developed to facilitate the horizontal (among MES solutions) and vertical (from planning to operations) integration of existing and future factory information systems. To make the factory better able to adapt to specialized orders, decision tools and knowledge agents that can collect relevant data will be developed. The use of software agent technology in the framework will allow it to grow and evolve intelligently over time and adapt to additional end-user environments. SMART technologies will be designed to support a wide variety of manufacturing enterprises. If successful, the project should catalyze the acceptance and availability of factory floor information solutions and lower the risk to both users and vendors of the technology. The broad use of integratable MES will in turn increase the competitiveness of manufacturers by reducing downtime and increasing efficiency, enabling companies to react to rapidly changing business opportunities and compete more successfully in the global market.

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PARTICIPATING ORGANIZATIONS:

Advanced Technology Program
General Motors Corporation - North American Operations Research Analytics
IBM - Stamford CT
International TechneGroup Incorporated
MESA International
NIIIP
STEP Tools, Incorporated
UES Incorporated
University of Florida

70NANB8H4018

Title: **Integrated Simulation Environment for Photonics Manufacturing**

Start Date: 02/01/1999

End Date: 02/01/2000

Total Activity Funding: $10,736K

Abstract: Although photonics technology is becoming more important in communications, imaging, data storage, and other systems, the U.S. photonics industry is struggling. A key deficiency is the lack of an open development framework and integrated simulation tools for evaluating photonic components, systems, and network designs quickly, reliably, and inexpensively before they are built. An eight-member consortium led by Bell Communications Research plans to develop an open, multilevel computer simulation environment that will reduce the time and costs associated with manufacturing photonics components by a factor of five while also increasing reliability and yield. The planned system will accommodate an expandable library of tools that can generate designs at the network, equipment, component, and device levels. Efficient data exchange will enable designers to predict the effects of changes at one level on other levels. In addition to developing and validating the models and tools, the consortium will optimize overall system performance. The key technical challenges will be to achieve sufficient accuracy and speed of prediction at all levels as well as adequate integration, both among the new tools and between them and the existing electronics simulation framework. The ATP funding will enable the joint venture partners--commercial and academic software developers and vendors, photonics designers, and manufacturers of photonics systems and network equipment--to design an open, integrated simulation environment with interoperable tools instead of pursuing proprietary subelements of the system to meet individual needs. If successful, the project will help the U.S. photonics industry prosper in a growing market. The new technology will be applied first in the communications sector but also will help reduce costs and improve products in many other industries, including medicine, transportation, computers, defense, and entertainment. The other partners are Lightwave Microsystems Corp. (Santa Clara, Calif.) ; RSoft, Inc. (Ossining, N.Y.) ; Science Applications International Corp. (McLean, Va.) ; SDL, Inc. (San Jose, Calif.) ; Columbia University (New York, N.Y.) ; and Nortel Networks (McLean, Va.). A key subcontractor is Hewlett-Packard Co. (Westlake Village, Calif.). This project is co-funded by the NIST Advanced Technology Program (ATP)

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PARTICIPATING ORGANIZATIONS:

Advanced Technology Program
Bell Communications Research Incorporated
Columbia University
Hewlett-Packard Company Inc
Lightwave Microsystems
Nortel Networks
RSoft Incorporated
Science Applications International Corporation
SDL Incorporated

IOF-23

Title: **Design of Fluids-Based Processes Associated with Glass Manufacturing**

Start Date: 04/07/1998

End Date: 09/30/2000

Total Activity Funding: $10,400K

Performing Organization: Sandia National Laboratories

US Department of Energy, Office of Defense Programs

Date Funding Last Modified: 04/07/98

We are developing validated simulation and process design tools for predicting the flow, chemistry and solidification/drying/curing of materials. We have applied our capabilities to material processes for ceramics, polymers and metals and can readily apply the same simulation capabilities to molten glass, up to the point of forming and annealing. We have developed a unique computational capability, GOMA, for simulating and designing materials processes. GOMA is a multi-dimensional simulation capability that solves the coupled thermal, fluid, structural and chemical species conservation laws for complex fluid flows in deforming geometries with free and moving boundaries. It can also simulate phase-change, viscoelasticity and other complex material processes/properties. Applications areas, beginning with flow/deposition, drying, curing and solidification processes have been simulated successfully with GOMA flow/deposition, drying, curing and solidification processes have been simulated successfully with GOMA and we are validating the mechanisms within this capability for coatings and metals processing. This capability has been applied to the simulation of a variety of materials processes including coatings (ceramic and polymer), encapsulation, extrusions, remelting, and soldering. In addition, these capabilities readily apply to the fluid mechanics-based aspects of glass manufacturing, like extrusion and float zone processing. We are currently extending this capability to permit the determination of stability windows for materials processes. Our approach, based on linear stability analysis, will permit the determination of process sensitivity to perturbations around specified operating states. As such, process deviations resulting in material imperfections, such as macro-segregation during solidification, and deviations resulting in other product defects, such as thickness or shape non-uniformities due to mechanical disturbances, can be avoided.

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PARTICIPATING ORGANIZATIONS:

DOE Office of Defense Programs
DOE Office of Energy Efficiency and Renewable Energy
Sandia National Laboratories

70NANB5H1128

Title: **Fabrication Of Advanced Structures Using Intelligent And Synergistic Materials Processing**

Start Date: 09/01/1995

End Date: 09/01/1999

Total Activity Funding: $10,189K

Abstract: Whoever first observed that "a chain is only as strong as its weakest link" probably knew something about heavy equipment. Heavy manufacturing machines, including surface- transportation equipment and off-road construction equipment, must withstand vibration and cyclical loads. The "weak link" often is a welded joint--fatigue cracking of welds is the limiting factor in the design, use, and life of this equipment. Prevailing welding operations produce welds with a large variability in strengths and resistance to fatigue, and the prudent designer, of course, goes with the most pessimistic values. The entire situation presents opportunities for dramatic improvements in structural performance as well as cost savings. But welding is a complex process, and successful welds are a combination of many factors, including the composition of the base metals, the geometry of the weld, the stresses introduced in the parts before, during, and after welding, and of course the welding operation itself. Bits and pieces of research have been done on all of these elements, but the interplay and contribution of all these factors to the strength of the weld is only imperfectly understood. The joint venture assembled by Caterpillar Inc. proposes a broad program to combine and integrate research developments in automated welding, welding power sources, welding consumables, process sensors, intelligent control systems, advanced process-simulation tools, with "weld-compatible" steel and aluminum material processing. Project objectives are to increase dramatically fatigue performance of welded joints in conventional steel and aluminum fabrications, which will extend fatigue life significantly and/or increase the allowable fatigue stress. Other members of the joint venture include an on-highway truck chassis fabricator, A.O. Smith (Milwaukee, WI) ; a welding equipment supplier, The Lincoln Electric Co. (Cleveland, OH) ; and a material supplier, U.S. Steel (Pittsburgh, PA). This project is co-funded by the NIST Advanced Technology Program (ATP)

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PARTICIPATING ORGANIZATIONS:

AO Smith
Advanced Technology Program
CATERPILLAR, INC.
Lincoln Electric Company
US Steel - Pittsburgh PA

00-00-4061

Title: **Coating-Enabled Component Design/Technology Tools for Nanostructured Coatings**

Start Date: 11/01/2000

End Date: 10/31/2004

Total Activity Funding: $9,588K

Abstract: Develop improved process-control technologies, models and design tools to enable reliable design of gears and other precision machine components with advanced nanometer-scale coatings for enhanced wear and performance characteristics in heavy equipment.

Advanced coatings constructed on the nanometer scale could greatly enhance the performance of machine components, such as truck and aerospace transmissions, but such coatings currently cannot be produced with enough repeatability to enable the design of reliable components with complex shapes. Caterpillar Inc., United Technologies Research Center (East Hartford, Conn.), and J.A. Woollam Co., Inc. (Lincoln, Neb.), plan to develop improved design tools and processes for complex components that exploit the performance advantages offered by nanostructured coatings, and to demonstrate their use in making more powerful and efficient gears. Coatings are typically applied by placing parts in a vacuum chamber containing an ionized gas from which the coating is built up atom by atom. In the four-year project, the partners will develop a sensor-based system for controlling and assuring the quality of coatings as they are deposited to eliminate inconsistencies that currently result from inadequate process control. The team will also develop new methods for measuring critical coating properties and the mechanisms that control their performance, and for applying these properties onto complex shapes. Physics-based life prediction models for coated systems will be developed that incorporate wear-dependent changes, unlike current models. The new models will focus on how microstructural details affect gear failure modes. Finally, new gear geometries will be designed based on the physical property maps, performance characteristics, and life prediction models, with a goal of achieving a 25 percent improvement in power density and 5 percent less friction, with a consequent improvement in fuel economy. Several subcontractors will assist in the project. The ATP funding enabled the formation of the joint venture; none of the partners could undertake this long-term research alone. If successfully developed and commercialized, the new technologies will lead to lighter, more efficient, more durable power transmission gears and other machine components, thereby offering consumers greater efficiency and reliability and reduced costs. Aerospace transmissions could be made more powerful, for example, and warranty and maintenance costs in the heating, ventilation, and air conditioning compression industry could be reduced. Benefits to the economy, especially the auto industry, could exceed $6 billion annually.

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PROJECT PARTICIPANTS:

United Technologies Research Center (East Hartford, CT)
Caterpillar, Incorporated - Technical Center/Advanced Materials
J.A. Woollam Co., Inc.

99-01-3026

Title: **Open Software Tools for Condition Based Maintenance**

Start Date: 11/01/1999

End Date: 10/31/2002

Total Activity Funding: $9,383K

Abstract: Develop planning and decision-support technologies for enterprise-wide, cost-effective, condition-based maintenance operations.

Condition-based maintenance has become a key tool for efficiency and cost savings in many U.S. plants. Condition-based maintenance systems use sensors, automated diagnostics, and predictive models to schedule equipment maintenance when the machine actually needs it -- neither too soon, as might happen with simple preventive maintenance schedules, nor too late. One of the major benefits is that CBM minimizes the time that equipment is out of service -- for this reason the concept has been embraced in situations where down time is very expensive, such as for combat aircraft or high-volume auto assembly lines. But CBM can also dramatically reduce the costs of maintenance through better management of the complex web of parts suppliers and maintenance firms that make up the maintenance supply chain. Those systems that exist are expensive, unique, custom designed, point solutions. CBM has not been widely implemented outside of the high-end industries mentioned largely because the initial costs to set up such a system are high. United Technologies Corporation has entered into a joint research venture with i2 Federal, Inc., (Irving, Texas) with the goal of simplifying and lowering the introductory cost of CBM by developing and demonstrating a set of generic, widely applicable software tools for value assessment, planning, design and implementation of enterprise-wide condition-based maintenance. A comprehensive enterprise-wide CBM system involves incredible complexity. A machine-wear model might have to track thousands of individual units, each with hundreds of factors to be tracked and modeled; each maintenance action may involve a specific supply chain of spare parts, repair actions, vendors, required staff skills, and the like. As a result, there have been no general software solutions to large-scale implementation of CBM. Because of the sheer size and complexity of the generic problem, this project involves substantial technical barriers. In particular, the optimization tools will involve significant advances in the state of the art. ATP funding will permit the partners to move beyond simple point solutions for their own needs to develop a more broadly applicable CBM toolset for U.S. industry. The partners anticipate that at least $30 billion in maintenance costs in the U.S. economy could be saved annually through widespread use of CBM.

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PROJECT PARTICIPANTS

i2 Federal Systems (Irving, TX)

98-02-0061

Title: **DataPipes**

Start Date: 10/01/1998

End Date: 10/01/2001

Total Activity Funding: $8,454K

Abstract: Develop infrastructure technologies to enable low-cost manufacturing of high-capacity optical data links, which could overcome bandwidth limitations in computing and communications networks and increase productivity in many industries.

Exponential increases in computer processing speed soon will outpace advances in the data-carrying capacity of the cables and wires that connect the elements of computing and communications networks. A logjam is likely if interconnections are not improved. A vertically integrated team of six companies led by 3M will develop scalable infrastructure technologies to enable low-cost manufacturing of multiple generations of wide, parallel optical data links offering roughly 10 times the capacity of the best available commercial technologies. To achieve high link performance at low cost, the research team will develop an array of new technologies. These will include precision-molded ceramic connectors, transceivers consisting of optoelectronic devices integrated with low-cost integrated circuits (or chips) to reduce the number of parts and simplify assembly, "smart link" controls to adjust performance and relax manufacturing tolerances, low-cost alignment techniques for mating optoelectronic devices to fiber arrays, and modeling and simulation tools for redesigning links to achieve new performance objectives. The companies plan to make and test a 36-fiber demonstration link. The target data rate for each fiber is 1 to 2 gigabits per second, with manufacturing costs comparable to conventional copper wires. If successful, the project could enable U.S. companies to dominate the market for ceramic multifiber connectors, projected to reach $3 billion by 2006. Productivity would rise in many industries because cost-effective supercomputing would be possible using clusters of inexpensive desktops. Spin-off benefits could include high-precision ceramic components for the medical and automotive industries and optoelectronic component subassemblies for printing, bar-code scanning, and sensors. The other partners in the joint venture are Honeywell Technology Center (Minneapolis, Minn.) ; RSoft, Inc. (Mountain View, Calif.) ; Coors Ceramics Co. (Golden, Colo.) ; CFD Research Corp. (Huntsville, Ala.) ; and Precitech, Inc. (Keene, N.H.). Simulation software will be developed by the Center for High Technology Materials at the University of New Mexico (Albuquerque, N.M.).

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PROJECT PARTICIPANTS:

Honeywell Technology Center (Minneapolis, Minn.)
RSoft, Inc. (Mountain View, Calif.)
Precitech, Inc. (Keene, N.H.)
Coors Ceramics Company (Golden, Colo.)
CFD Research Corporation (Huntsville, Ala.)

70NANB5H1054

Title: **High-Performance Composites For Large Commercial Structures**

Start Date: 02/01/1995

End Date: 09/01/1998

Total Activity Funding: $6,724K

Abstract: Developers of advanced materials for non-military applications are frequently confronted by a catch-22. They cannot bear the high financial risk of development without assurance that end users will buy the new materials, but end users are unwilling to lend such assurance without first getting familiar with the materials in question. This situation is particularly relevant to the usage of polymer matrix composites--polymeric materials reinforced with fibers--in the civilian sector even though composites do not deteriorate the way traditional infrastructural materials such as wood, steel, and concrete do. A vertically integrated core of material suppliers (DOW and Brunswick Technologies, Inc.) and part fabricators (DuPont and Hardcore Composites, Inc.), who are strongly linked to end users in the civil infrastructure communities, propose to break through this impasse. The heart of the project is to take the recently invented Seeman Composite Resin Infusion Molding Process (SCRIMP) from a hand- labor-intensive, craftsman-like process to an advanced manufacturing practice. Particular challenges include developing specific manufacturing protocols to make the parts as well as computer models that will enable engineers to readily design parts capable of performing specific roles; developing new manufacturing tools complete with networks of sensors that provide feedback for more precise control; and integrating many technology components into one efficient process that can yield quality composite parts at least 30 percent less expensively than the present process while delivering products to customers in half of the time. Additional participants in the project include The Johns Hopkins University. Subcontractors include the University of Delaware and DOW-UT. This project is co-funded by the NIST Advanced Technology Program (ATP)

POINT OF CONTACT: Brian Belanger, 301-975-2162

PARTICIPATING ORGANIZATIONS:

Advanced Technology Program
Brunswick Technologies Incorporated
E I DuPont de Nemoirs
Hardcore Du Pont Composites
Johns Hopkins University
University of Delaware

5.0 Best Manufacturing Practices Related to Modeling & Simulation for Manufacturing

Title: **Advanced Amphibious Assault Vehicle (AAAV) Development**

Abstract: The Advanced Amphibious Assault Vehicle (AAAV) government/contractor team of Marines, government civilians, and contractor personnel are co-located in the AAAV Technology Center in Wood-bridge, Virginia. This team is revolutionizing acquisition processes to reduce total program cost, condense acquisition cycle time, and leverage commercial best practices to design, test, field, and support the most capable, cost effective combat vehicle in the world.

The AAAV Program initiated a process known as "Virtual Integration and Assembly (VI&A)," for use during the fabrication of three full scale vehicle prototypes in PDRR phase. VI&A creates computer based assembly drawings and instructions from Computer Aided Design (CAD) models of the AAAV which are used by assembly mechanics on the shop floor. The program bypasses the antiquated, costly process of generating and maintaining blueprint-style paper drawings. VI&A also contains a Problem Reporting System which permits real-time capture of assembly problems as they are discovered. VI&A has also permitted prototyping processes that are not traditionally initiated until the Engineering, Manufacturing, and Development (EMD) phase, reducing acquisition cycle time and processes required during EMD. It further permits collection of significant data applicable to production line analysis before the end of PDRR, thereby condensing acquisition lead-time. VI&A also promises substantial cost avoidance potential by producing graphics and procedures directly from VI&A for assembly, disassembly, and mainte-nance to be used for embedded training and Interactive Electronic Technical Manuals (IETMs). Future expansion of VI&A will permit problem reporting during field tests, allowing field technicians to access the full CAD database, mark up drawings, and e-mail changes directly to design engineers. The end result will deliver the AAAV to the operating forces with higher quality and lower total program cost.

PARTICIPATING ORGANIZATIONS:

MARCORSYSCOM, DRPM (AAA), http://www.acq-ref.navy.mil/sstories/

BMP-HARRIS-02

Title: **Best Modeling Practices**

Abstract: Because companies in the semiconductor industry rely on bringing new products quickly to market to remain competitive, there is a constant effort to reduce the product-to-market cycle time. One critical component to reducing this cycle time is the application and improvement of CAD tools and their related models that provide the basis for circuit simulation and verification. To improve the overall prod-uct-to-market cycle times and manufacturability of its end products, Harris initiated development, deliv-ery, and continuous improvement of the SPICE models and modeling systems.

The Harris Modeling Team was tasked with delivering Revision X models (Revision 0 through Revision 3) for existing and new processes (technologies) according to resource commitments, customer priorities, and maps defining what was desired, commonly referred to as Should-Be Maps; implementing the Should-Be Modeling Maps and procedures for new and existing processes; and ensuring the modeling maintenance map is implemented.

The enhanced design process resulting from this effort included the use of fabrication data, parametric data gathered during wafer testing, and modification and improvement of SPICE models. This practice was directly applicable to Harris Semiconductor's market strategy that focused on analog and mixed signal circuits whose yields are determined more by parametric properties than defect densities.

CAD modeling and Monte Carlo simulations at Harris now use statistically-based data such as a parameter's mean and standard deviation versus the nominal. This practice prevents blindly placing a certain percentage tolerance around a nominal for worst case studies when there is no data to support that tolerance. Model predictions are more accurate using parametric data. First time success of a new product and continued high yields therefore become commonplace. Two technologies whose models are advanced in the model rating criteria, but not yet at the highest criteria, have been used by Harris engineers and customers for analog ASIC designs. They achieved a 100% first-pass success rate, 26 of 26, versus a more traditional 20% success rate.

POINT OF CONTACT: Andre Blanc, (407) 729-561

PARTICIPATING ORGANIZATIONS:

Harris Semiconductor

BMP-LMTAS-02

Title: **Conceptual Design Environment**

Abstract: LMTAS uses an internally-developed CAD system called ACAD during conceptual design to provide the best opportunity to reduce total product cost. ACAD provides LMTAS the capability to concurrently evaluate manufacturing, tooling, factory, and enterprise concepts with product concepts, and to rapidly construct conceptual virtual prototypes. These virtual prototypes are used for early cost evaluation. ACAD also has an interactive capability through high-speed data transfer lines with other sites to provide real time, individual interaction with all connected sites.

Development of ACAD was initiated in 1982 and now contains over 800,000 lines of code. The effort was undertaken because there were no commercial tools for LMTAS's needed capabilities. ACAD's customized features include:

- Rapid lofting of advanced surfaces
- Geometric associativity to facilitate rapid iterative design modifications
- Rapid area, volume, and center of gravity analysis tools
- Aerodynamic center analysis
- Advanced meshing interface to radar cross section (RCS) and computational fluid dynamics (CFD)
- Rapid structural modeling; weight and cost prediction
- Carrier suitability analysis tools
- Stereolithography interface
- Obscuration (vision) plots
- Rapid solid modeling
- Ray tracing cavity analysis
- Built-in animation/simulation

The ability to rapidly generate multiple structural models with associated weight and cost estimates is a major benefit for design optimization in the early stages of product development. Integrated simulation (Figure 2-5) allows many assembly and manufacturing processes to be proofed well in advance of hardware availability, thereby avoiding costly fabrication of mock-ups.

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PARTICIPATING ORGANIZATIONS:

Lockheed Martin Tactical Aircraft Systems

BMP-TI-01

Title: **Concurrent Engineering Tools**

Abstract: TI DSEG maintains that a key concurrent engineering concept is to provide design and producibility guides to the design team early in the development stage before committing to downstream functions or hardware. Consequently, TI DSEG developed a dual-faceted approach providing guides through Specialty Engineering Analysis Tools and through Product Design and Manufacturing Process methodologies. Using this approach, TI DSEG has realized shorter development cycles, reduced developmental costs, and improved product quality. In some cases, the required breadboards and brassboards have been reduced or eliminated.

There are several specialty Engineering Analysis Tools that enable the design engineer to make informed decisions by embedding rules in the design process. An example of this concept is the Manufacturing Rules Checker (MRC), a software tool that analyzes the actual PWB design database and denotes potential problem areas. MRC's 54 rules check component placements prior to routing the board. Interferences and questionable components can then be repositioned by the designer and the board can be routed. The Investment Casting software package is another engineering analysis tool and uses a question-and-answer decision tree to guide engineers through various casting features and helps avoid pitfalls. The tool addresses 50% to 60% of casting design basics, leaving more complex issues to be addressed by the casting producibility personnel. The MIL-STD-2000 Checker navigates the designer through a 30-item checklist and generates a report indicating compliance or non-compliance. The major benefit of these and other TI developed tools such as the Interconnect Expert System, Tolerance Analysis and PWB Expert System is early problem detection, resulting in cost effective corrective actions.

TI DSEG's Product Design and Manufacturing Process is supported not only through the specialty tools, but also through Design Centers. Design centers consist of some combination of four workstation configurations - Systems Engineering, Mechanical Engineering, Electrical Engineering, and Software Engineering. The workstations are distributed by project, functional area, or individual designer needs and provide a wide range of design, simulation, and analysis capabilities for the various TI DSEG products.

TI DSEG's combination of tools, controls, and functions provide the basis for a successful concurrent engineering effort. The functions in the developmental cycle (see graphic) are tied by the product/process information needs. The workstations/design centers provide the mechanisms to accomplish the functions, while the rule-based specialty systems control the function execution.

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Texas Instruments, DS&EG (Raytheon TI Systems)

BMP-LMTAS-03

Title: **Design Integration with COMOK**

Abstract: LMTAS integrates several design tools to serve company-specific needs. For example, LMTAS selected CATIA (a solid modeling package) as the core design software. LMTAS has identified several specific design functions not available with commercial software and has chosen to customize or build software to serve these specific needs. COMOK provides an example of enhancing commercially-available CATIA software to satisfy LMTAS specific needs.

Although CATIA is a robust design tool, it did not satisfy all LMTAS integrated product development needs. Concurrent, integrated product development is enabled by the dynamic sharing of design iterations. The COMOK database management system is the technology that provides centralized access to multiple configurations defined geometrically by CATIA solid models. As new programs are initiated, COMOK is used in place of metal mock-ups. Since it is available at the start of the design process, it improves design integration and quality.

As COMOK provides a tool for design integration, it also serves to cross organizational boundaries, integrating the conceptual and detail design with the manufacturing and assembly process development. The digital database is populated by engineering and tooling component iterations throughout the development phase of a program, and is used by many functions within the integrated product teams. As component parts are integrated, COMOK provides automated utilities checks for interferences and clearance requirements. With this integrated product development functionality, COMOK is used to communicate design changes to those affected. After the design has been released, the database is used for follow-on design and analysis activities throughout the product's life cycle.

LMTAS realized the implications of limiting access to the conceptual model during the fluid design phase. As a result, it has few restrictions governing the modification of component parts in the fluid design phase. Once the design is finalized, it is released and changes are accomplished within Engineering Change Notice guidelines.

COMOK is currently implemented on the FS-X, F-22 (team-wide), F-16U, and F-16 Singapore programs with over 900 active participants. The F-22 program takes the integrated functionality one step further by allowing the design partners such as Boeing, Lockheed Marietta in Georgia, and LMTAS to share common data during the integrated product development phase. On this program, there are approximately 1400 megabytes of information shared between the multi-company partnership.

The design integration has had a significant and positive impact on quality, schedule, and cost. Quality improvements are realized through fewer design iterations, a well-integrated product, maximum data reuse, fewer 'surprises,' and verification of design and tooling integration. This product performs schedule compression as planning, design, analysis, and manufacturing planning are performed concurrently. On the F-16 program, design change cycle time has been reduced from eight months to three months. Also, the need for metal mock-ups is essentially eliminated.

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BMP-CDI-02

Title: **Design Process Improvement**

Abstract: Computing Devices International applies CAE tools to improve its ASIC design process. By increasing simulation software use and migrating to the latest versions of simulation software with greater performance and flexibility, design cycle time has been significantly reduced as well as the number of costly design iterations. In addition, flexibility in vendor choice is now a capability even after design definition because of improvements in the Hardware Description Language (HDL).

Computing Devices International has capitalized on improvements in hardware/software simulation tools to refine the ASIC design process. Each new level of simulation capability has led to significant reductions in design iterations and cycle times. Current design practice includes the use of Verilog HDL (Cadence), Synopsis gate level design generation software, high and low level simulations using Verilog and a hardware modeler (Logic Modeling Systems Inc.) which provides interface to a real microprocessor, and LSI Logic Gate Level simulation tools (LSI's LCAP, FSIM, LTEST, and LBOND) for timing analysis and test vector generation.

These tools reflect the following improvements in the design process:

- Design developed manually
- Design generated automatically using HDL and Synopsis
- Reduced time to generate design; consistency in design approach
- Design entered via schematic capture
- Design entered directly through HDL
- Reduced time to simulate and design
- Separate high and low level simulations
- HDL approach provides direct link
- Greater effectiveness in design verification
- Gate level simulation using behavioral model
- Gate level simulation using actual microprocessor in the hardware modeler
- Greater effectiveness in design verification
- Design is vendor specific
- Design non-vendor specific through HDL with vendor libraries
- Greater flexibility in choice of vendor

Use of these tools has resulted in a design cycle time decrease from up to three years, to one year, to a projected time of eight months. Iterations have been reduced to less than 50% in spite of an increase in chip complexity from 40,000 gates to 85,000. Current projects are attempting to realize no design iterations on all developed ASICs.

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General Dynamics - Information Systems

BMP-LMGES-03

Title: **Electromagnetic Performance Simulation**

Abstract: Design and optimization of complex microwave devices/systems previously required extensive physical experimentation to expedite evaluation and selection of design approaches at LM-GES. Highly skilled personnel in electromagnetic theory were needed to derive complete analytical solutions, and scientific programmers skilled in numerical methods to code and debug analytical solutions. These processes were time consuming and expensive to perform since a failed design required substantial work to reformulate solutions and reprogram new design approaches.

However, by using commercial and proprietary computer-based analytical simulation tools to design and optimize complex microwave devices/systems, LM-GES has reduced the development time by at least 50%. A physical simulator built to validate computer simulation and verify final design and manufacturing processes is used to authenticate the computer simulation, provide feedback for tuning of the analytical model, and verify fabrication and assembly processes (Figure 2-1).

Using simulation, cycle time has been reduced by 50%, manpower reduced from two work-years to six work-months, system performance improved through computer statistical optimization techniques, and required skills shifted from highly specialized theorists and programmers to broad-based microwave engineers.

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PARTICIPATING ORGANIZATIONS:

Lockheed Martin Government Electronic Systems

BMP-NG

Title: **Factory Process Modeling and Simulation**

Northrop Grumman's Simulation and Virtual Manufacturing Tools team developed Factory Process Modeling and Simulation for some sections of the F/A-18 C/D assembly line. Through modeling and simulation, the company can continuously make improvements in quality and productivity, and evaluate new ideas, methods, and actions. Simulation tools can develop utilization profiles for resources; allow Integrated Product Teams to plan and analyze possible scenarios; predict production system behavior without disrupting ongoing operations; and identify processes where lean manufacturing practices will have the greatest impact.

As a test case, the team modeled the production operations of Cost Center 2510 (the Aft Center Fuselage Assembly). First, the team developed an assembly precedence model using Microsoft project. This model identified critical paths and opportunities for shortening the process cycle. Next, the model was fine tuned via input from the mechanics working on the production line. Then the model was exported from Microsoft Project, translated, and imported into the Autosimulations Autosched software. A graphic simulation model of the Center was developed in the Autosched software. To populate the model, data was downloaded from 35,000 lines of production scheduling and the Integrated Management, Planning, and Control for Assembly system. Other types of data used in the simulation included operator data such as quality certifications, efficiency/experience, difficulty of tasks, and job preference qualifications. The team devised and ran numerous simulation experiments to vary the parameters (e.g., operator efficiency, number of operators, work shift hours, number of nonconformances, quality assurance processing time).

Through this modeling and simulation effort, Northrop Grumman identified opportunities for a 10% cost reduction in the Center's operation. Simulations were also used to determine the best course of action to deal with part shortages occurring at the Center. The company was able to define and analyze possible scenarios for handling the shortages in a three-hour timeframe. Northrop Grumman is now applying its Factory Process Modeling and Simulation to other production areas within the company. A detailed simulation model of the Composites Center has already been developed.

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PARTICIPATING ORGANIZATIONS:

Northrop Grumman Corporation
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BMP-RAY-01

Title: **Integrated Circuit Design/Software**

Abstract: Raytheon began developing microwave and millimeter-wave monolithic integrated circuit (MIMIC) technology in the late 1970s to accommodate the manufacture of small, low-cost microwave components. This effort has resulted in devices with a ten-to- one reduction in size and cost compared to hybrid components commonly used in today's systems. The device development and the tools Raytheon MSD created to support the design of the MIMIC components are equally impressive.

Approximately two years ago, Raytheon MSD's CAD group began developing software tools to help microwave designers create predictable circuit designs. Existing tools could not support these designs because the circuit paths became components - inductors and capacitors - at these frequencies. This phenomenon therefore required the design tools to simultaneously take into account the effect and design the artwork. Until that time, there had been no software to support the designs except rudimentary idealized circuit simulators. Consequently, most of the design process was manual and required several prototypes.

CADENCE CAD software was already being used by Raytheon MSD for lower frequency designs. The software developers wanted to use available capture, layout, and simulator tools and sent engineers to CADENCE to learn its architecture and work with CADENCE to add microwave design enhancements to their package. The software development, completed in 1991, has produced dramatic results. Raytheon MSD presented the following impact on their MIMIC designs.

Raytheon has contributed its developments to CADENCE provided that CADENCE would continue to enhance the package and maintain it. Consequently, all parties have benefited from this effort. Raytheon MSD developed the CAD technology to a necessary capability and will now have a company to update and maintain it. CADENCE has a marketable product and their customers can share in a very useful technology that might have otherwise been proprietary.

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Raytheon Company

BMP-MDAW-01

Title: **Numerical Control Simulation/Verification**

Abstract: MDA-West utilizes software packages designed for verification of NC programs that substantially reduce the proofing cycle of NC codes while improving first time quality and reducing costs. NC programmers generate programs from electronic engineering models, and these NC programs, run on Hewlett-Packard dedicated workstations, are simulated and verified using Vericut TM software available from CG Tech. The software demonstrates the programmed cutting of a solid model including cutting tools and parameters. This allows the programmer to verify the NC program results in a part configuration matching the engineering model.

MDA has also written software packages to ensure the correct tool definition is maintained through the program and correct procedures are used which are not included in the Vericut TM program. After verifying the NC program, a post-processor generates the specific machine control language. Because the generic data can be converted incorrectly resulting in invalid motion statements, MDA has created a reverse post-processor to verify the final code.

Implementation of this NC program verification system has greatly enhanced first time quality. Although the NC programmer spends approximately 10% to 25% more time preparing the program, hardware is correct the first time at a rate of 99%.

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McDonnell Douglas Aerospace - West (Boeing Space Systems)

BMP-NG-07

Title: **Tool Design from 3-D Modeling Data**

Abstract: Prior to implementing its modeling software, Northrop Grumman used conventional 2-D drawings for designing tools and equipment. This method required the company to maintain a tremendous amount of paperwork to record revisions and corrections per tooling specifications. These revisions, as they were incorporated, went through lengthy approval loops prior to being introduced to the assembly floor and, in remote instances, caused the production lines to be halted. Another barrier was the inability to accurately align components from one Cost Center to the next, which often prevented adjacent components from properly aligning and caused long delays in the production cycles.

Northrop Grumman now uses Unigraphics 3-D modeling software to design its tools and equipment. Since implementing the modeling software, the company has minimized its design cost requirements of new tooling as production requirements increase or as new prototypes come on-line. This modeling software provides an on-line review of changes as they are incorporated into the production cycle without interrupting the Cost Centers' schedules. In addition, the Cost Centers have access to the changes as they occur.

Northrop Grumman estimates its design times, ranging from 8 to 450 hours, via four groupings: very simple; simple; complex; and highly complex. Although its design engineering lead times have doubled since implementing the software, the company has reduced its fabrication times from six weeks to two weeks. In addition, the producibility factor has essentially eliminated any misalignment defects normally associated with 2-D drawing packages. This single factor alone has increased the throughput of each Cost Center and decreased the number of Shop Floor Action Items associated with 2-D drawings. The cost of implementing and networking this modeling software is estimated at $200 thousand, compared to the

$300 thousand cost for an average assembly jig. Other benefits include finite element modeling; stress reduction recognition; and the ability to maneuver the model assemblies into various axial positions, allowing engineers to identify possible problem areas.

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